NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS OF OPERATIONAL PACE VERSUS LOGISTICAL SUPPORT RATE IN THE GROUND COMBAT ELEMENT OF A MARINE EXPEDITIONARY BRIGADE

by

Roy Miner

September 2006

Thesis Advisor:	Arnold Buss
Second Reader:	David Schrady

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2006	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Analysis of Operational Pace Versus Logistical Support Rate in the Ground Combat Element of a Marine Expeditionary Brigade			**5. FUNDING NUMBERS**
6. AUTHOR Roy Miner			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT

The execution of maneuver warfare by the Marine Air Ground Task Force (MAGTF) places a large amount of stress on the supporting logistics infrastructure. Sustaining the movement of the Ground Combat Element (GCE) as the battlefield expands becomes increasingly difficult to accomplish by the Combat Service Support Element (CSSE) with finite assets. We assert the days of supply the GCE is capable of carrying, the reorder point for inventories carried by the GCE, and the transportation capacity assets within the CSSE dedicated to moving supplies are all significant contributing factors in sustaining the movement of the GCE. This thesis defines a logistics process and develops a simulation where the GCE consumes logistical resources necessary to sustain its movement toward assigned objectives while being supported by a CSSE in an expanding maneuver warfare environment. We define a successful sustainment of the GCE and using logistic regression, confirm the above three factors contribute significantly to the success rate of sustainment in the simulation. Through regression and leverage plots we determine which of the three factors contribute significantly more to the responses of success and time. We also conclude through a sample means comparison the combination of factor values that achieve a minimal delay in sustainment for the GCE in the simulation.

14. SUBJECT TERMS Combat Service Support, Logistics, Discrete Event Graphs, Discrete Event Simulation, Java Computer Language Programming, Time Criteria Logistics Model, Transportation, Logistic Regression, Regression Analysis			**15. NUMBER OF PAGES** 99
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

ANALYSIS OF OPERATIONAL PACE VERSUS LOGISTICAL SUPPORT RATE IN THE GROUND COMBAT ELEMENT OF A MARINE EXPEDITIONARY BRIGADE

Roy Miner
Captain, United States Marine Corps
B.S., California State University, Hayward 1998

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 2006

Author: Roy Miner

Approved by: Arnold Buss
Thesis Advisor

David Schrady
Second Reader

James N. Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The execution of maneuver warfare by the Marine Air Ground Task Force (MAGTF) places a large amount of stress on the supporting logistics infrastructure. Sustaining the movement of the Ground Combat Element (GCE) as the battlefield expands becomes increasingly difficult to accomplish by the Combat Service Support Element (CSSE) with finite assets. We assert the days of supply the GCE is capable of carrying, the reorder point for inventories carried by the GCE, and the transportation capacity assets within the CSSE dedicated to moving supplies are all significant contributing factors in sustaining the movement of the GCE. This thesis defines a logistics process and develops a simulation where the GCE consumes logistical resources necessary to sustain its movement toward assigned objectives while being supported by a CSSE in an expanding maneuver warfare environment. We define a successful sustainment of the GCE and, using logistic regression, confirm the above three factors contribute significantly to the success rate of sustainment in the simulation. Through regression and leverage plots we determine which of the three factors contribute significantly more to the responses of success and time. We also conclude through a sample means comparison the combination of factor values that achieve a minimal delay in sustainment for the GCE in the simulation

THIS PAGE INTENTIONALLY LEFT BLANK

THESIS DISCLAIMER

The reader is warned that the computer simulation developed and employed in this research may not have been exercised in all cases of interest. Every effort has been made to ensure the programs and data are free of computational, logic, and collection errors with the time available. However the simulation cannot be considered validated. Any use of this program or data without further verification is at the risk of the user.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ABBREVIATIONS AND ACRONYMS

AAV	Amphibious Assault Vehicle
ACE	Air Combat Element
ACE	Armored Combat Earthmover
CE	Command Element
CSSD	Combat Service Support Detachment
CSSE	Combat Service Support Element
DCM	Distribution Capacity Management
DE	Distribution Executer
DOS	Days of Supply
DPM	Distribution Production Management
FEL	Future Event List
GCE	Ground Combat Element
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HSD	Honestly Significant Difference
ICM	Inventory Capacity Management
IE	Inventory Executer
IFAV	Interim Fast Attack Vehicle
LAV	Light Armored Vehicle
MAGTF	Marine Air Ground Task Force
MCSSD	Mobile Combat service Support Detachment
MCWP	Marine Corps Warfighting Publication
MDC	MAGTF Distribution Center
MEB	Marine Expeditionary Brigade
MPG	Miles Per Gallon
OM	Order Management
RM	Request Management
ROP	Reorder Point
TAMCN	Table of Allowance Material Control Number
TC	Transportation Capacity
TCL	Time Criteria Logistics
TF	Task Force

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENT

I would like to first acknowledge Professor Arnold Buss and express my gratitude for his guidance and instruction during the process. Professor David Schrady's insight, experience, and opinion have been a valued asset during my time here at the Naval Postgraduate School. I would also like to take a moment to thank all the professors whose instruction I have had the pleasure of being under during my time at this academic institution. I would like to thank my family whose warmth and appreciation has provided a source of inner strength.

Finally, I would like to express my appreciation and gratitude to my wife, Heather, for her patience, understanding, and support throughout this study. The reminder of her presence and faith in my life has kept me grounded and courageous.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The requirement of maneuver warfare to conduct operations at a rapid tempo places a large amount of stress on the supporting logistics infrastructure. Combatant elements within a Marine Air Ground Task Force (MAGTF) can consume and expend resources at a rapid rate while advancing toward mission objectives. The chief logistics resources that are consumed during maneuver warfare by a MAGTF would be Class I (Food and Water), Class III (Fuel), and Class V (Ammunition) types of supply. The Combat Service Support Element (CSSE) of the MAGTF is responsible for responding to the logistics needs of the MAGTF Ground Combat Element (GCE) in order to sustain its movement. Yet interruptions to the advance of the GCE can occur due to the expanding distance of the battlefield.

A variety of factors can possibly contribute to the interruption of an advance toward objectives but in a logistics process the main interruption is a failure in logistics sustainment. There are three main factors and their relationship to sustainment that are studied in this thesis. The amount of days of supply a GCE is capable of carrying would seem to suggest a relationship in the length of time the GCE can be sustained. Obviously if a GCE is capable of carrying fourteen days of supply it should be able to sustain its movement for fourteen days. Yet burdening the GCE with days of supplies is counter intuitive to maneuver warfare and thus the factor will be included in the study. The reorder point at which a GCE requests supplies would seem to suggest a relationship as well. If the GCE exhausts the on-hand inventories of supplies that facilitate its movement before ordering additional supplies it will obviously cause the GCE to cease its movement until additional supplies are distributed by the CSSE. The third factor involves the finite transportation capacity resident within the CSSE. The CSSE only has limited resources and assets dedicated to the transportation and distribution of supplies to the GCE. If supplies are consumed by the GCE in amounts that exceed what the CSSE can distribute back to the GCE then movement of the GCE will inevitably be interrupted

and sustainment will have failed. By varying the values and levels of these three factors we can demonstrate the importance they have in sustaining the movement of the GCE to its assigned objectives.

Specific accomplishments of this thesis are:

- Defining a logistics process: Using discrete event graphs a logistics process can be developed using the concepts of the arrival process and the service process. The consumption of supplies can be represented as an arrival process where scheduled events and self-scheduling events drive the demand for supply consumption. As an event that consumes inventory is scheduled there is a reduction in the on-hand inventory supply resident within a combat unit. The need to request supplies can be represented as a service process. When on-hand inventories reach a reorder point level a request for additional supplies can be made. A wait delay is initiated to determine when the supplies will arrive and the end service is accomplished at the end of the wait delay.

- Developing a simulation: Simkit is a Java based discrete event simulation tool that facilitates the transition of the discrete event graph for the logistics process to Java programming code. Using Simkit allows this thesis the advantage of studying the dynamic interaction between logistics support and operational pace over time. It also allows greater flexibility over a network model since the continuously increasing cost of time for distribution of logistics would be difficult to implement and measure.

- Identifying significant factors: By alternating the combinations of factors and their respective levels this thesis is able to identify which factors are of significant importance in determining the successful sustainment of the GCE in the simulation. It also assists in determining which factors possess the stronger relationship to the response variables of success and time to reach assigned objectives by the GCE.

I. INTRODUCTION

A. BACKGROUND

In April of 1983 the Commandant of the Marine Corps instituted the permanent fixture of the Marine-Air-Ground-Task-Force (MAGTF) concept. The intent was to establish an expeditionary force that would be readily deployable and able to respond to an arising crisis in any geographical corner of the globe. The MAGTF concept became the preferred fighting method of the United States Marine Corps (USMC) due to its optimal combined arms capability. The MAGTF consists of four elements: the Command Element (CE), the Ground Combat Element (GCE), the Aviation Combat Element (ACE), and the Combat Service Support Element (CSSE). The CE serves as the headquarters for the MAGTF and provides command and control, intelligence, and other support that enables effective planning and execution of operations by the other elements of the MAGTF. The GCE is task-organized to conduct ground operations for the MAGTF. It is normally centered on a Marine infantry unit(s) with combat support units attached to form a Landing Team. The ACE is task-organized to conduct air operations and provides all or a portion of the six functions of marine aviation to enable the MAGTF to accomplish its mission. Finally, the CSSE is task-organized to provide support necessary for the MAGTF to accomplish its mission. The support available from the CSSE for the MAGTF normally covers all the functional areas of Marine Corps logistics (supply, maintenance, transportation, engineering, health services, and other services).

The introduction of the MAGTF has permitted the Marine Corps to pursue its warfighting philosophy of maneuver warfare. Maneuver warfare avoids the direct confrontation with the enemy involved in attrition warfare. It seeks to bypass enemy strengths and attack their critical vulnerabilities in order to render them incapable of resisting effectively rather than engaging them directly and seeking their destruction through superior firepower. Exploiting and destroying an enemy's critical vulnerabilities will incapacitate the enemy systematically and reduce their capability of fighting as a coordinated whole. Maneuver warfare involves executing a rapid and focused offensive in order to create a turbulent environment in which the enemy functions and disrupt the enemy's ability to respond in a counter maneuver. Speed is a primary weapon in

maneuver warfare and the ability to create and maintain a turbulent environment in which the enemy functions demands a rapid operational tempo on the part of the MAGTF.

1. Logistics Principles and Support for the MAGTF

The CSSE is the main logistics supporting element for the MAGTF and it attempts to employ all seven principles of logistics when supporting the overall MAGTF mission: responsiveness, simplicity, flexibility, economy, attainability, sustainability, and survivability. According to MCWP 4-1 "these principles, like the principles of war, are guides for planning, organizing, managing, and executing. They are not rigid rules, nor will they apply at all times. As few as one or two may apply in any given situation" (MCWP 4-1). When supporting maneuver warfare, the most paramount of these logistic principles is responsiveness, simplicity, and sustainability. Analyzing these three principles individually with respect to maneuver warfare can provide some insight into their importance.

"Responsiveness is the right support in the right place at the right time" (MCWP 4-1). Given the high operational tempo that is required to execute maneuver warfare, responsiveness of logistical support is difficult to achieve. Logistical resources that are being carried by the combat elements of the MAGTF during combat operations are consumed at a rapid rate. Combat elements require these resources to be replenished at a rate commensurate to the rate at which they are consuming them in order to maintain an operational pace over time when executing maneuver warfare.

"Simplicity fosters efficiency in both the planning and execution of logistics operations" (MCWP 4-1). Maneuver warfare attempts to create a confusing and turbulent environment in which the enemy is forced to function. Yet the speed that maneuver warfare requires also creates a confusing and turbulent environment for the MAGTF. Tracking friendly units, inventorying supplies, cataloguing requisitions, and other basic tasks can prove to be overwhelming in a maneuver warfare environment. A logistical infrastructure designed around simplicity can facilitate the distribution of logistics support to the combat elements when conducting maneuver warfare.

"Sustainability is the ability to maintain logistics support to all users throughout the area of operations for the duration of the operation. Long-term support is the greatest

challenge for the logistician, who must not only attain the minimum, essential material levels to initiate combat operations (readiness) but also must maintain those levels for the duration to sustain operations" (MCWP 4-1). Sustainability is probably the most important logistics support principle in regards to maneuver warfare. Without sustainability the operational tempo of maneuver warfare is hampered if not halted.

2. Logistics Support and Maneuver Warfare

The requirement of maneuver warfare to conduct operations at a rapid tempo places a large amount of stress on the supporting logistics infrastructure. Within the MAGTF the combatant elements expend and consume resources at a rapid rate when executing maneuver warfare. The chief logistics resources consumed by a MAGTF during maneuver warfare are Class I (Food and Water), Class III (Fuel), and Class V (Ammunition) types of supply. The CSSE is responsible for responding to the logistics needs of the MAGTF combat elements in a simple and expeditious manner in order to sustain operations for the complete duration of the mission. The frequency at which the combatant elements request logistics support depends on a variety of factors, the most important being the type of mission to be executed and the enemy situation. Both the mission and the enemy situation dictate the rate at which the combat elements of the MAGTF move toward their objective. The frequency of requests also depends on the capacity with which the combat elements are self sustaining, i.e. how many days of logistic resources are they carrying within their unit. The more resources the unit carries internally the longer the unit can remain self-sustaining while conducting operations before requiring additional support.

The rate at which the CSSE can provide support and sustain the movement of the GCE also depends on a number of factors. Three are identified for this thesis. The first is the amount of days of supply the GCE is capable of carrying in its on-hand inventories. Burdening the GCE with excessive days of supply is counter intuitive to maneuver warfare and eliminates the need for a CSSE. If the duration of a GCE's mission exceeds the amount of days of supply in its on-hand inventories the GCE will rely on the CSSE to replenish those on-hand inventories.

The second factor is equipment available for direct and general support. The amount of equipment available for support determines the distribution capacity the CSSE

possesses to provide the combatant elements with resources and supplies. If the requirements of the combatant elements exceed the capacity available to support them then the combatant elements will be short of replenishing their logistic requirements. Total equipment availability is determined by equipment dedicated for direct and general support.

The third is the point at which the GCE reorders its on-hand supplies from the CSSE. As the battlefield extends itself and the distance between the supporting CSSE and the GCE increases a greater elapsed time between request and delivery of supplies is experienced. The point at which the GCE reorders its supplies can determine whether enough on-hand inventory remains within the GCE to sustain its operational pace until the arrival of additional supplies from the CSSE occurs.

Other conditions that can affect the rate the CSSE can provide support is the changing battlefield and the rate at which the CSSE can accomplish logistics tasks. In reference to the changing battlefield, the total requirement of logistic resources necessary to support an operation is usually located at a fixed position be it onshore or sea based. During maneuver warfare, as the MAGTF combat elements drive toward their assigned objectives they increase the distance of the battlefield in width and depth. This increases the distance required to travel for resource distribution from the fixed logistical supply to the combatant elements. Yet the speed or rate at which a vehicle carries resources to the MAGTF element does not fluctuate. Therefore as the battlefield grows so also does the time it takes to transport supply support to the combatant elements of the MAGTF. This contributes to reducing the rate the CSSE can provide support.

Accomplishing required logistics tasks also contributes to the rate at which the CSSE can provide logistics support. The time required to complete logistics tasks will vary from task to task. When resources are required by the combatant element it is not automatically known by the CSSE. A certain number of system processes take place to comprise each individual logistic task. Communication is established with the CSSE and the requisition for resources (material or services) is relayed. The requisition is processed and passed to the supporting unit. Organization and planning takes place to fulfill the requisition. Finally the support request is executed until completion. These tasks all take

time to process and complete. Adding this processing time to the transportation of supply support reduces the overall rate the CSSE is able to provide logistics support to the GCE.

3. Time Criteria Logistics Model and MAGTF Distribution Study Scenario

The Time Criteria Logistics (TCL) Model is a study prepared by Decision Engineering of Woodbridge, VA for the United States Marine Corps. Its purpose "was to establish a time criteria for Marine Expeditionary Brigade logistics tasks and demonstrate how the established criteria supports capacity and resource management…Time planning factors were developed for the logistics processes required to support a Marine Expeditionary Brigade" (Decision Engineering, 2004). The TCL Model outlines a number of logistics tasks and the time needed to complete them. The tasks are broken down into processes required to complete the given logistics task. Each process has an associated triangular distribution of time required to complete the process. This thesis will use the TCL Model to determine time required to complete logistics tasks in support of a GCE within a Marine Expeditionary Brigade sized MAGTF.

The MAGTF Distribution Center (MDC) Study possesses a two hundred day scenario for a Marine Expeditionary Brigade conducting ship to objective maneuver in the year 2015 time frame. For the purposes of this thesis the units and background of the scenario will be approximated but the scope of the scenario will be narrowed to the first fourteen days involving the initial assault of an objective and the follow-on assault of another objective by the MAGTF combatant elements. This thesis will focus on the availability of ground support provided to the GCE by the CSSE in order to sustain ground combat operations and maintain operational tempo during the initial and follow-on assault phases of the scenario.

B. RECENT STUDIES AND THESIS GOAL

This thesis studies the relationship between the pace of ground combat operations during maneuver warfare and the rate at which logistical support can sustain this pace. As the operational pace extends the battlefield an increased stress is placed on the established logistics infrastructure that reduces the rate which resources can be supplied

to the ground combat elements. This thesis studies this relationship and the effects it has on sustaining the ground combat operations during the initial stages of the assault.

This thesis will focus on three factors that contribute to this relationship of operational pace and its sustainment through the logistics infrastructure. The three factors of interest are days of supply the GCE is capable of carrying, the reorder point for on-hand inventory supplies within the GCE, and the amount of transportation capacity assets resident within the CSSE dedicated to moving supplies to the GCE.

With these three factors in mind a study into their significance will be conducted. An effort will be made to show the significance between the factors and the successful sustainment of the GCE through the development of a logistics process, a discrete event simulation of that process, and an analysis of the output data from the simulation. An effort will also be made to establish the proportional significance of each factor in relation to the other factors. Alternating realistic levels will be developed for each factor and an attempt to identify combinations that result in the least amount of sustainment delays will be made.

Assistance in this study is made possible by the Time Criteria Logistics Model (Decision Engineering, 2004), the MAGTF Distribution Center Concept Study (Concurrent Technologies Corporation, 2005), and the US Marine Corps Ship to Objective Maneuver Concept of Operations (2003).

II. MODEL DEVELOPMENT

This chapter introduces the development of the discrete event simulation model for the logistical process used in this thesis. It first introduces discrete event graphs and their use in simulation modeling. The chapter then presents a general outline of four generic yet relevant logistical events that occur when a GCE moves toward an objective. It then demonstrates specific logistics processes and events involving different supply classes. Finally a complete graphical representation of the total logistics process is exhibited with comments concerning necessary input factors.

We first define the general logistical process of a moving combat unit and a supporting logistical unit. This general process serves as the foundation for developing the specific logistical processes that are used in this thesis.

A. DISCRETE EVENT GRAPH MODELING

Discrete event simulation is a modeling paradigm in which the model's state remains constant except for particular events, which can take place at any place or time (Law and Kelton, 2000). Events are scheduled by the simulation and placed in a Future Event List (FEL) to occur sequentially over time. Time is advanced in discrete steps during the simulation to initiate the earliest scheduled event in the event list. Event graphs are a graphical way of representing discrete event simulations (Buss, 2001). There are many elements in an event graph. The ones we are chiefly concerned with are the following: state variables, events, scheduling edges, and parameters. With these elements we can use event graphs to represent discrete event simulation models. We take a moment to define each of the listed elements:

1. State Variables

State variables are associated with events and transition over time from one value to another as the associated event occurs. They are used to capture performance measures of the discrete event simulation. Time varying statistics and data can be collected on each state variable within an event graph to produce these performance

measures. State variables are defined in the margins of an event graph and are normally listed below the events they are associated with.

2. Event

An event is a significant occurrence of a state transition where the values of state variables can change within the discrete event simulation. In an event graph an event is normally represented by a circle with the title of the event residing within the circumference of the circle.

3. Scheduling Edges

A scheduling edge is a directed edge between two events. The event from which the edge originates schedules the event where the edge terminates to occur by placing the scheduled event in the FEL. In an event graph it is represented by a solid line with an arrowhead pointing to the terminating event.

a. Time Delays

Time delays are associated with scheduling edges in a discrete event graph. A time delay is a delay in the occurrence of an event. When an event is scheduled it can occur immediately or it can occur after an elapsed amount of time has passed. In the event a time delay is instituted the scheduled event will occur later in the simulation after the indicated time delay has elapsed. Time delays are represented at the originating point of a directed edge with an event graph.

b. Conditionals

Conditionals are also associated with scheduling edges. A conditional is a statement of conditional logic. It is usually associated with scheduling and canceling edges. In the instance a conditional statement is imposed on a scheduling or canceling edge the conditional logic of the statement must be met in order to enact the associated directed edge. A conditional statement is represented by a character symbol centered on the associated directed edge with the conditional statement above the character.

4. Canceling Edges

A canceling edge, like a scheduling edge, is a directed edge between two events. The main difference is the event from which the edge originates keeps a previously

scheduled event from occurring. The event where the edge terminates is the previously scheduled event. A canceling edge is represented by a dotted line with an arrow head pointing to the cancelled event.

5. Parameters

A parameter is an agent in the discrete event simulation that assists in determining the results of the simulation. Time delays are an example of a parameter. Parameters can also be passed along directed edges. This is represented as a box on the respective edge with a parameter value within the box. Essentially, the value of the parameter is passed from an originating event to the scheduled event. The value of the passed parameter will be used during the processing of the scheduled event and will be represented by the character symbol in parentheses inside the circumference of the scheduled event. Parameters are usually listed and defined by name in the margins of an event graph.

B. GENERAL CASE OF A LOGISTICS PROCESS

A logistics process will be defined as the process through which an entity consumes logistical resources and is replenished with logistical resources over time. For the purpose of this thesis the logistical resources will be specific classes of supply. Within the MAGTF there are two military entity types and four relevant events involved in logistics processes that occur over time. The two military entities are classified as a supported unit and a supporting unit. For simplicity and the purpose of reducing confusion, a supported unit will be referred to as a combat unit. The four events that occur over time can be classified as supply consumption, request supplies, deliver supplies, and return of transportation. We expand upon these classifications in the following paragraphs for the principle effect of developing a foundation for the simulation model and corresponding event graph.

A combat unit is a unit that moves at a specified rate and carries on-hand inventories of logistic supplies to assist in sustaining its rate of movement during a logistical process. The supporting unit is a unit which remains fixed at a single location. At its location it possesses supplies that are necessary to sustain the movement of the combat unit. The supporting unit has a delivery rate and available transportation capacity to move supplies to the combat unit during a logistical process. The delivery rate in a

supporting unit is simply the rate of movement the supporting unit can transport supplies over a given distance. Available transportation capacity in a supporting unit is the maximum amount of capacity at a given time the supporting unit can commit for the purpose of moving specific supplies from its location to the combat unit.

Supply consumption is the expenditure of logistical supplies over time that is carried on hand within a military unit. The supplies must be present within a unit's on-hand inventory for it to be consumed. As a supply is consumed the unit's on-hand inventory is reduced by the amount consumed. The consumption of supplies can either be self-scheduling or dependent on the occurrence of a prior event. In the instance that a consumption event is self-scheduling there is a time delay between consumption events. For the general purpose of this definition and for purposes of the event graph below in Figure 1 it will be assumed that a consumption event will be self-scheduling.

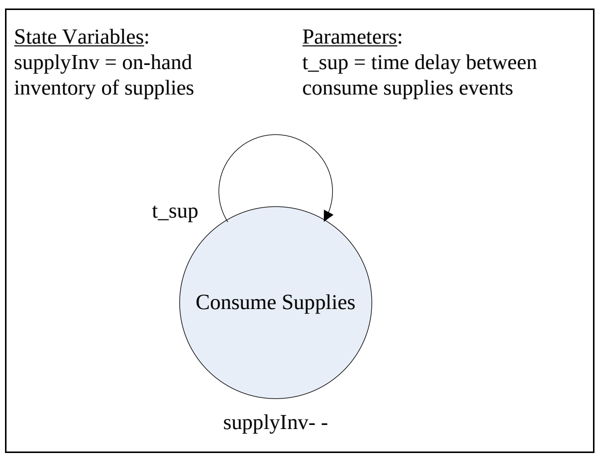

Figure 1. Supply Consumption Event Graph

The request supplies event is an event that is conditionally scheduled by the supply consumption event. As the on-hand inventory of supplies within a military unit is reduced over time it becomes necessary for the combat unit to request additional logistical supplies. This prevents the on-hand inventory from being reduced to a level that would prove inadequate in sustaining the military unit's movement toward an objective. The point at which this request is made is determined by an established reorder point. The request is made when the on-hand inventory is reduced below the established reorder point. The quantity of supplies requested can vary but for the

purposes of this general definition it will be the difference between the current on-hand inventory and the maximum supply capacity that the military unit can carry within its on-hand inventory. When supplies are requested the request event allots the amount of required transportation capacity to move the requested supplies. This is done by reducing the amount of available transportation capacity within the supporting unit by the amount of supplies requested by the combat unit. Figure 2 demonstrates a graphical representation of the request supplies event in conjunction with the consume supplies event.

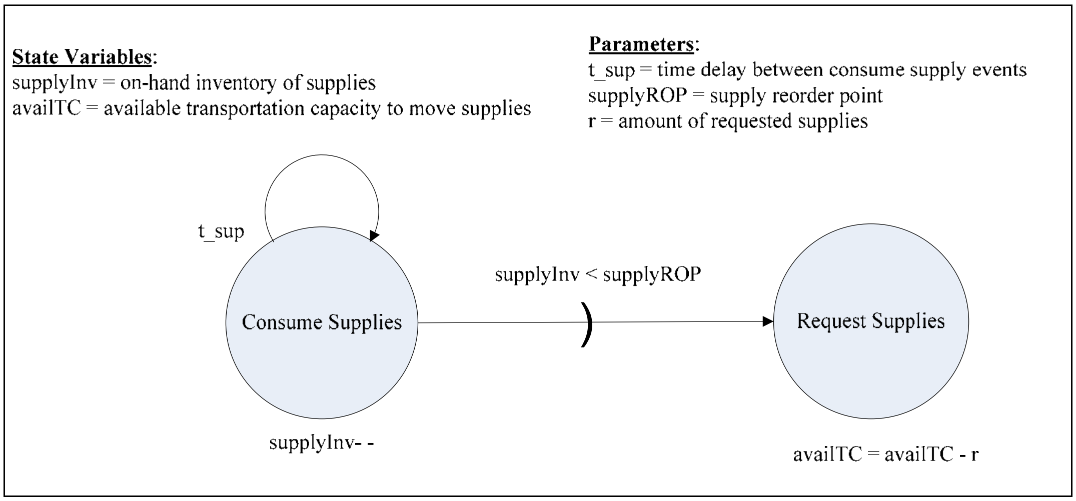

Figure 2. Supply Consumption with Supply Request Event Graph

The Deliver Supplies event occurs after the request supplies event. The requested amount is passed as a parameter to the deliver supplies event. The deliver event is scheduled with a time delay that depends on the time to process the supply request and the distance between the supporting unit and the combat unit. The amount of time required to process the supply request is a random variable. Further explanation of this random variable will be discussed in the following chapter. The amount of time required to move supplies from the supporting unit to the combat unit is determined by the delivery rate of the supporting unit. With the processing time and the time it takes to deliver the supplies we are given the total delay time before the supplies are actually delivered to the combat unit. When the delivery event occurs there is an increase in the on-hand inventory of supply for the combat unit. The on-hand inventory is increased by

the amount of supply that was initially requested. Figure 3 depicts a graphical representation of the delivery event included with the supply consumption and supply request events.

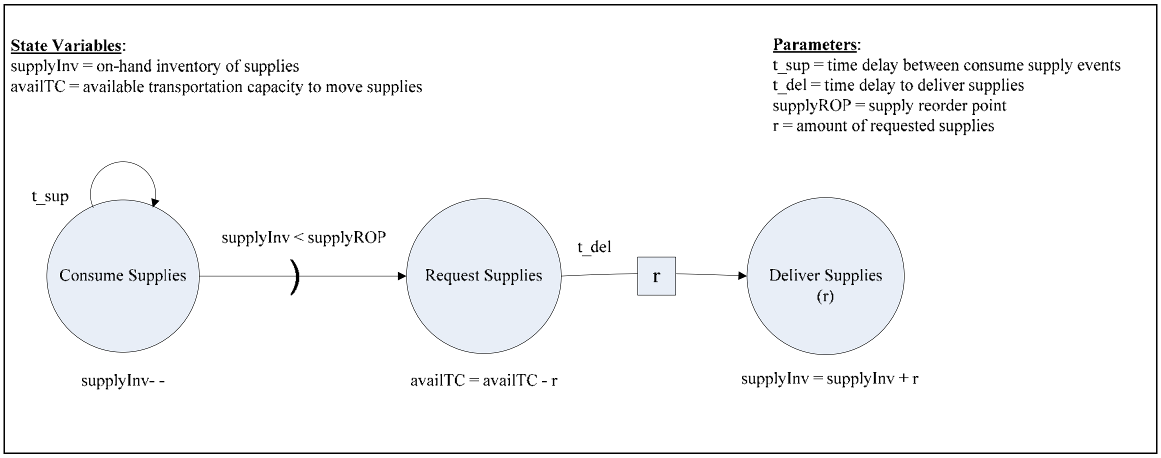

Figure 3. Deliver Supplies Event Graph

The final relevant event is the Return Transportation, an important event to include in a logistics process between a combat and supporting unit. The Return Transportation event is scheduled immediately after the deliver supplies event with a delay in time that relies on the distance between the supporting and combat units as well as the delivery rate of the supporting unit. Once the delivery event occurs the supply transportation capacity is no longer required by the combat unit. Yet the supply transportation capacity is still unavailable to be utilized by the supporting unit until it returns to the location of the supporting unit where additional supplies for transportation to the combat unit are located. When the return of transportation event occurs there is an increase in available transportation capacity owned by the supporting unit. The amount the available transportation capacity is increased by is the amount of supply that was originally requested. Figure 4 depicts a graphical representation of the Return Transportation event with the consumption, request, and delivery events. This concludes the general description of the logistics process between a combat and supporting unit. The following paragraphs will look at specific logistic events involving class I, III, and V types of supplies (water, chow, fuel, ammunition).

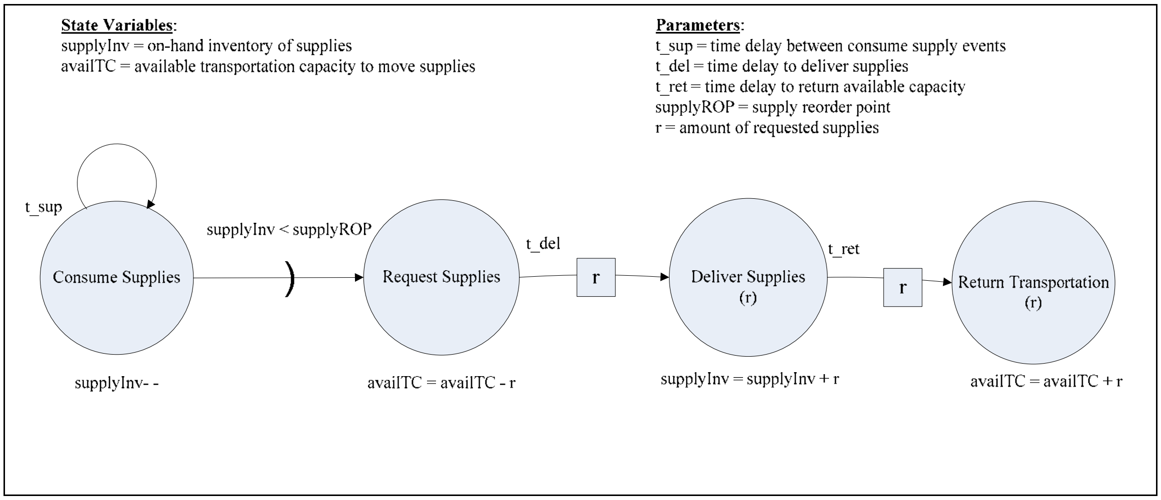

Figure 4. General Logistics Process

C. DISCRETE EVENT GRAPHS FOR SUPPLY CLASSES

The GCE conducts maneuver warfare to achieve its objective when engaged in an assault operation. As mentioned in chapter one, there are three primary classes of supply that a GCE consumes when conducting maneuver warfare. They are Class I (water and chow), Class III (fuel), and Class V (ammunition) types of supply. Discrete event graphs will now be exhibited for the logistics process of each type of supply.

1. Class I Supplies

We now consider the graphical representation for the class I logistics process. The discrete event graph for class I supplies in a logistics process between combat and supporting units is very similar to the general case described above. Water and chow both belong to the same class of supply and will be included in the same logistics process. Yet consumption and transportation of chow and water differ greatly therefore the general case will have to be modified. However, the logistics process for class I supplies still retains the inherent nature of the general case. There are seven events involved in the class I logistics process. They are chow consumption, water consumption, request class I supplies, deliver class I supplies, return class I transportation capacity, movement, and stop movement. The graphical representation of the chow logistics process is displayed in Figure 5.

Similar to the general case, chow and water consumption are self-scheduling events. Chow consumption has a time delay parameter of eight hours. This time delay enables chow to be consumed by a combat unit three times in a 24 hour period. Water is consumed throughout the day and will have a time delay parameter of one hour. State variables are introduced at the consumption nodes to capture the amount of class I supplies consumed over time and the effect on the combat unit's on-hand inventory. The amount of chow and water consumed by the combat unit is dependent on the amount of personnel within the combat unit. There are two events the chow and water consumption events conditionally schedule. They are the request chow event and the stop movement event. As in the general case, the request chow event is conditionally scheduled when the combat unit's on-hand inventory of chow or water is reduced below a specific reorder point through consumption. A reorder point parameter is denoted on each scheduling edge that leads from the consumption events to the request event. For the purpose of this model there is an additional condition that must be met for the request event to occur. State variables have been added to the class I logistics process to represent whether there are active chow or water requests already existing within the process. An active request is a request for supplies that has been made but not delivered to the combat unit at the present time. This condition is necessary to prevent duplicate requests for supplies in the case there occurs additional consumption events prior to the delivery event.

The stop movement event is an event that halts the movement of the combat unit toward an objective. The event signifies the combat unit's on-hand inventory of class I supplies has been reduced to a point where it can no longer sustain its movement toward an objective. Therefore the stop movement event is conditionally scheduled by the consumption events and occurs when the combat unit's on-hand inventory of either chow or water reaches a predetermined level. The predetermined level in the case of this graphical representation is denoted by the parameters for stopping conditions. If the predetermined level was equal to zero then the stop movement event would ensue when the combat unit's on-hand inventory for chow or water is completely exhausted. Two boolean state variables are affected by the stop movement event and are listed beneath the respective node. The first state variable indicates that the combat unit is in a stopped state. The other indicates that the combat unit's level of class I supplies has reached an

unsatisfactory level. The last significant element of the stop movement event is the interruption of the movement event. A canceling edge, represented by the dotted line in Figure 5, runs from the stop movement event to the movement event in order to cancel the next scheduled movement of the combat unit.

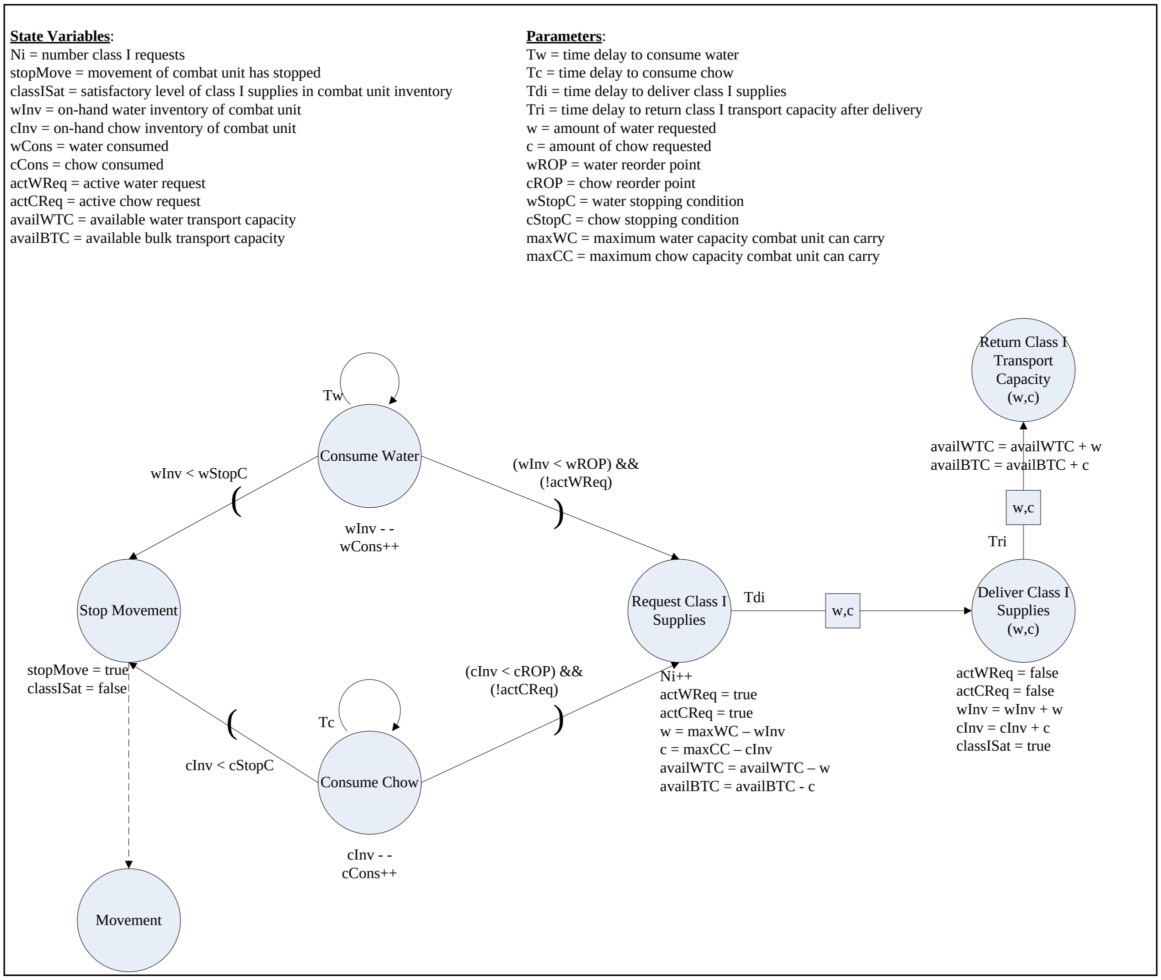

Figure 5. Class I Supply Logistics Process

When making requests for class I supplies it is rare that a combat unit will not request both chow and water at the same time, especially when depleted of either one. Failing to request both at the same time can place a heavier stress on the supporting unit and violates the economic principle of logistics. As demonstrated in the event graph either consumption event can schedule a request for supplies. When a request event is

scheduled the event allows for a request of both chow and water. State variables and parameters are listed beneath the request node to denote this. There are two boolean variables to indicate a chow and water request is now active within the class I logistics process when a request event occurs. The difference between the maximum on-hand inventory parameter and the state variable for the actual on-hand inventory determines the amount of chow or water to be requested. Finally, state variables for available transportation capacity are introduced for chow and water. The available transportation capacity is an element that is resident within the supporting unit. It corresponds to the amount of trucks and containers the supporting unit possesses for the purpose of moving supplies. The requirement for two state variables is exclusively due to the difference in physical nature or the requested items. Chow is a bulk substance and cannot be transported in a similar capacity to water. Water being a liquid is necessary to transport in a container capacity. As indicated in the event graph, both state variables for available transport capacity are reduced by the amount of chow and water requested.

The delivery event is scheduled by the request event. The time delay parameter between the request and delivery events is similar to the general case. It is dependent on the distance between the supporting and combat units as well as the time required to process a request by the supporting unit. The request event passes the requested amounts of chow and water along the scheduling edge to the delivery event. This is indicated by the boxed symbol on the corresponding edge between the two events. When the delivery event occurs both state transition variables for active chow and water requests become false and there is no longer an active request present in the class I logistics process. The state variables for the on-hand inventories are increased by the respective amounts requested and are considered satisfactory.

As in the general case, the event correlating to the return of available transport capacity is scheduled by the delivery event. The wait delay parameter between the two events is dependent on the distance between the supporting and combat units. The parameters for the requested amounts are passed between the two events as well. When the return event occurs the available bulk and water transport capacities are increased by the respective amounts that were requested by the combat unit. This event also completes the class I logistics process.

2. Class III Supplies

The discrete event graph for a class III supply logistics process between a supporting and combat unit is also similar to the general case but requires a few modifications. The main difference is the consumption of fuel is driven by the movement of the combat unit. Within the logistics process there are six events. They are movement, stop movement, fuel consumption, request class III supplies, deliver class III supplies, and return class III transportation capacity. The graphical representation for the class III logistics process is displayed in Figure 6.

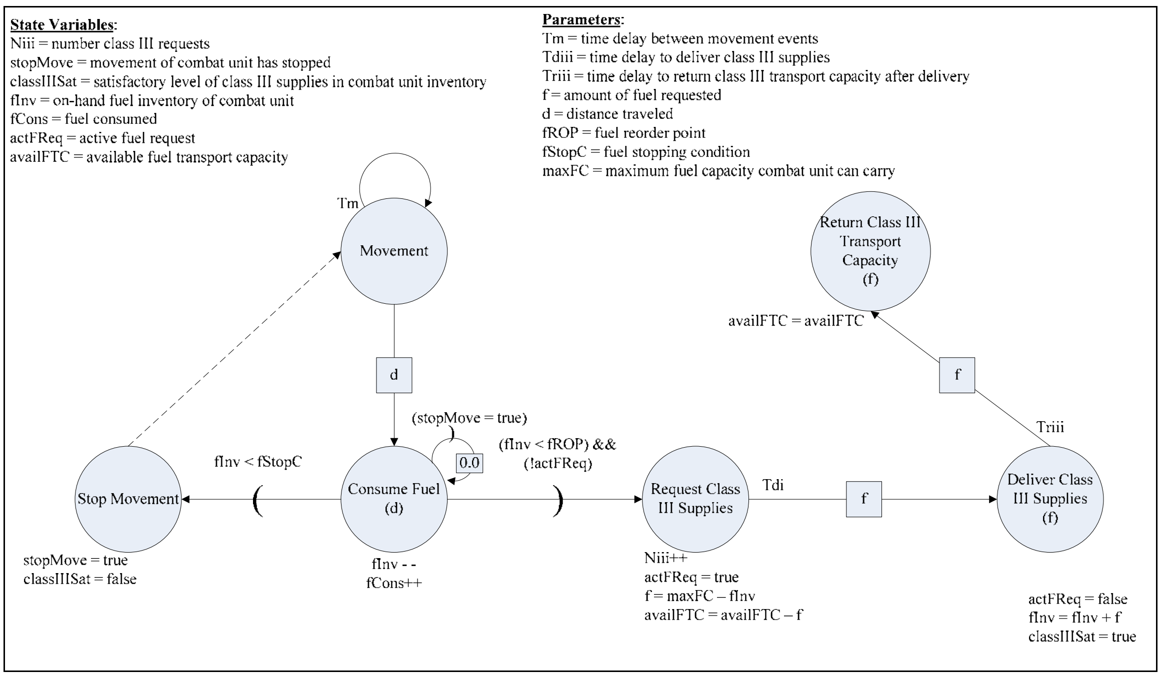

Figure 6. Class III Supply Logistics Process

We first consider the movement event. The movement event is a self-scheduling event with a time delay parameter to space out the calculated distance moved by the combat unit between each event. Although there is no location parameter associated with the movement event the logistics process does update the geographical location of the combat unit as a separate process. There is a scheduling edge from the movement event to the consumption event with no time delay parameter. A distance parameter is passed along the scheduling edge. In essence, as the combat unit moves it consumes fuel

immediately based on the distance traveled. It is in this respect that movement drives fuel consumption and differs from the general case.

Fuel consumed is determined by the distance traveled and equipment (e.g. generators) that are operated hourly. The conditional self-scheduling edge for the consumption event represents the consumption of fuel by equipment that continues to run despite the stopped state in which the combat unit may currently exist. As fuel is consumed the state variable for on-hand fuel inventory is updated as well as the state variable for total fuel consumption. If the on-hand inventory is reduced below the stopping condition parameter a stop movement event is scheduled without delay. In addition the boolean state variables for being stopped and having unsatisfactory inventory levels for fuel are updated. Once a stop movement occurs there is an immediate interruption to the next scheduled movement event. This is all represented in the event graph by the state variables listed beneath the consumption and stop movement nodes, the conditional self-scheduling edge, the scheduling edge between the consumption and stop movement events, and the canceling edge between the stop movement and movement events.

The remaining part of the graph is exactly the same, in principle, to the class I logistics process. Only the listed state variables and parameters are different. When there is no active fuel request present in the process and fuel consumption causes the combat unit's on-hand inventory to be reduced beneath the reorder point parameter a request of class III supplies event is scheduled without delay. This is demonstrated in the event graph by the scheduling edge between the consumption and request events. When the request event occurs the boolean state variable for an active fuel request is updated to indicate a request is present in the process. The amount of fuel to be requested is determined by the maximum on-hand inventory parameter and the current on-hand inventory. The state variable for available transport capacity resident within the supporting unit is reduced by the amount of fuel requested. A random wait delay parameter is determined between the request and delivery events. Again, this wait delay parameter is dependent on the amount of time required to process a fuel request and the distance between the combat and supporting units. The requested fuel amount is passed as a parameter from the request event to the delivery event. At the time the delivery

event occurs the state variable for an active fuel request is changed to indicate there is no fuel request present within the process. Also, the state variable for the combat unit's on-hand fuel inventory is increased by the requested amount and the level of class III supplies are catalogued as being satisfactory to sustain movement of the unit. The final portion of the event graph has the return of the available fuel transport capacity being scheduled by the delivery event with a time delay parameter. This time delay parameter is determined by the distance between the combat unit and the supporting unit. When the return event occurs the available fuel transport capacity within the supporting unit is increased by the originally requested amount. The originally requested amount is passed as a parameter between the delivery and return events. It is at this point the class III logistics process is concluded.

3. Class V Supplies

The discrete event graph for a class V supply logistics process is nearly identical to the class III supply logistics process. There are a few minor differences in the nature of the process, state variables, and parameters. The chief difference is the consumption of ammunition is driven by the enemy situation and the geographical location of the combat unit. Both of which rely on the movement of the combat unit. Within this logistics process there are six events. They are movement, stop movement, ammunition consumption, request class V supplies, deliver class V supplies, and return class V transportation capacity. The graphical representation for the class V logistics process is displayed in Figure 7.

As in the case with the class III logistics process, we consider the movement event first in the class V logistics process. The movement for this process is the same movement event as in the previous event graph. Normally consumption of ammunition would rely on the enemy situation. As the combat unit moves towards an objective it is normally assumed the enemy situation grows more and more hostile and violent, although this is not always the case. For this thesis, however, consumption rates for ammunition will be adopted from the MDC Study and expressed in terms of time. Thus, the consumption of ammunition will be at a steady rate as the combat unit moves with each time step. Since the movement event is a time scheduled event it will be the consumption event as indicated in the event graph.

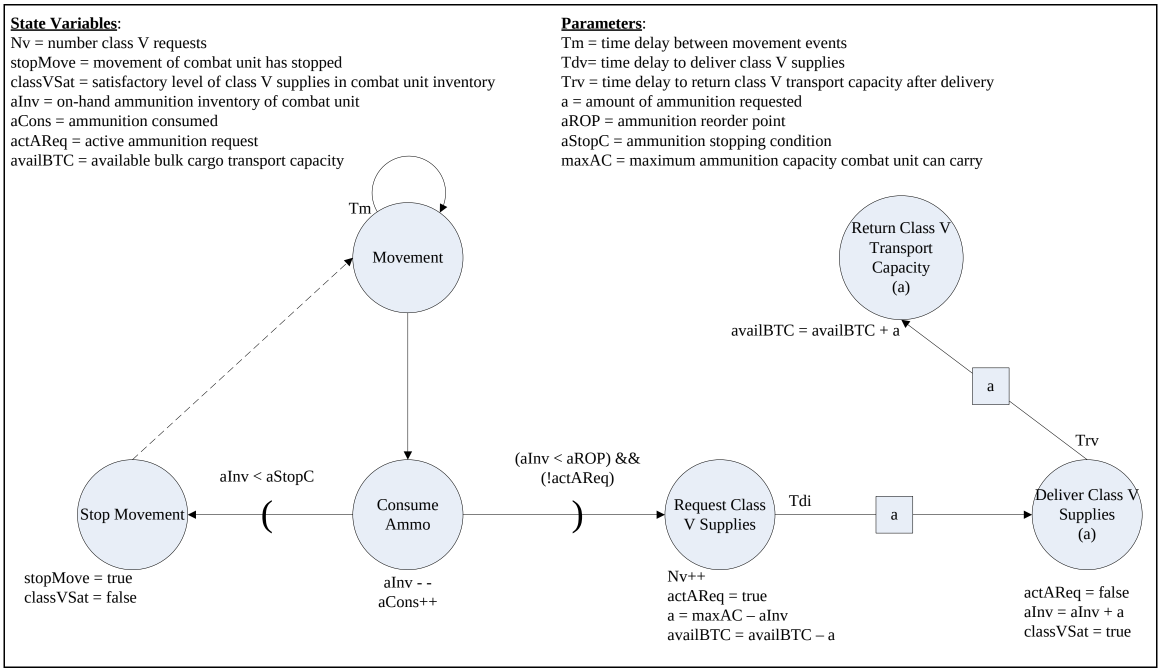

Figure 7. Class V Supply Logistics Process

As ammunition is consumed the state variables for on-hand ammunition inventory total fuel consumption is updated. If the combat unit's on-hand inventory of ammunition is reduced below the given stopping condition parameter a stop movement event is immediately scheduled. At the stop movement node the associated boolean state variables are updated to represent an unsatisfactory on-hand inventory level for ammunition and a cessation in movement by the combat unit. An immediate interruption of the next movement event is established as indicated by the canceling edge from the stop event to the movement event.

As ammunition is consumed there is a constant awareness of the on-hand inventory amount. Once the on-hand inventory is reduced beneath the reorder point, and assuming there is no active request for ammunition present in the system, a request for class V supplies is immediately made. This is shown in the graph by the conditionally scheduled edge between the consumption and request events. Once the request event occurs the amount of ammunition requested is determined by the difference between the maximum on-hand inventory parameter and the current on-hand inventory. The state variable for an active ammunition request is updated and the available bulk transportation

capacity is reduced by the requested amount. Again, a random wait delay parameter is determined between the request event and the delivery event that depends on the amount of time required to process an ammunition request and the distance between the combat and supporting units. The requested ammunition amount is passed as a parameter from the request event to the delivery event. When the delivery event occurs the state variable for an active ammunition request is updated. The state variable for the combat unit's on-hand fuel inventory is increased by the requested amount and the level of class III supplies are considered satisfactory. After the delivery event the return of bulk transportation capacity is scheduled with a time delay parameter that is determined by the distance between the combat unit and the supporting unit. It also passes the original requested amount as a parameter to the return event. At the moment the return event occurs the state variable for available bulk transport capacity within the supporting unit is increased by the originally requested amount. This event would complete the class V logistics process.

D. DISCRETE EVENT GRAPH FOR LOGISTICS PROCESS

The preceding sections of this chapter have presented in the fashion of discrete event graphs a representation for the different logistics processes. These logistics processes were for the general case and the three main classes of supply that are consumed during maneuver warfare. We now consider how these different logistics processes are incorporated together to form an encompassing logistics process between a combat and supporting unit while executing maneuver warfare. Figure 8 on the following page exhibits the graphical representation of this logistics process.

Viewing Figure 8, it is evident that the general logistics case is inherent within the graph. The consumption, request, delivery, and return events are all present in the logistics process. Each of the logistics processes for the three supply classes have been added in as separate segments and linked by the movement event. And all state variables and parameters that were introduced in the previous logistics processes are listed together in the graph. There is only one additional element added to the graph that was not present in the previous logistics processes, the second listed movement event node which is conditionally scheduled by each of the delivery events. The movement event node is

simply listed twice to avoid congestion within the graph. The second node is, for all practical purposes, the same movement event listed toward the top of the graph. Scheduling edges lead from each of the delivery events to the movement event. These directed edges are necessary to complete the cyclical nature of the logistics process. The previous graphs had stopping conditions that would interrupt the movement of the combat unit due to inadequate supplies needed to sustain movement. However, once the stop movement event occurred there was no manner in which the combat unit could start moving again. By adding conditional scheduling edges from each delivery event to the movement event the model allows the combat unit to commence movement again. This is, of course, under the condition that the combat unit is not already stopped and all on-hand supply inventories are at acceptable levels to sustain the combat unit's movement.

We now have a fundamental model for a simulation using Discrete Event Graph techniques. The graph allows the model to be coded in Java using the Simkit DES library as the implementing software package. In the following chapter a specific scenario is described and the output data from the simulated model will be analyzed. Input data values for parameters and variables will be presented and discussed.

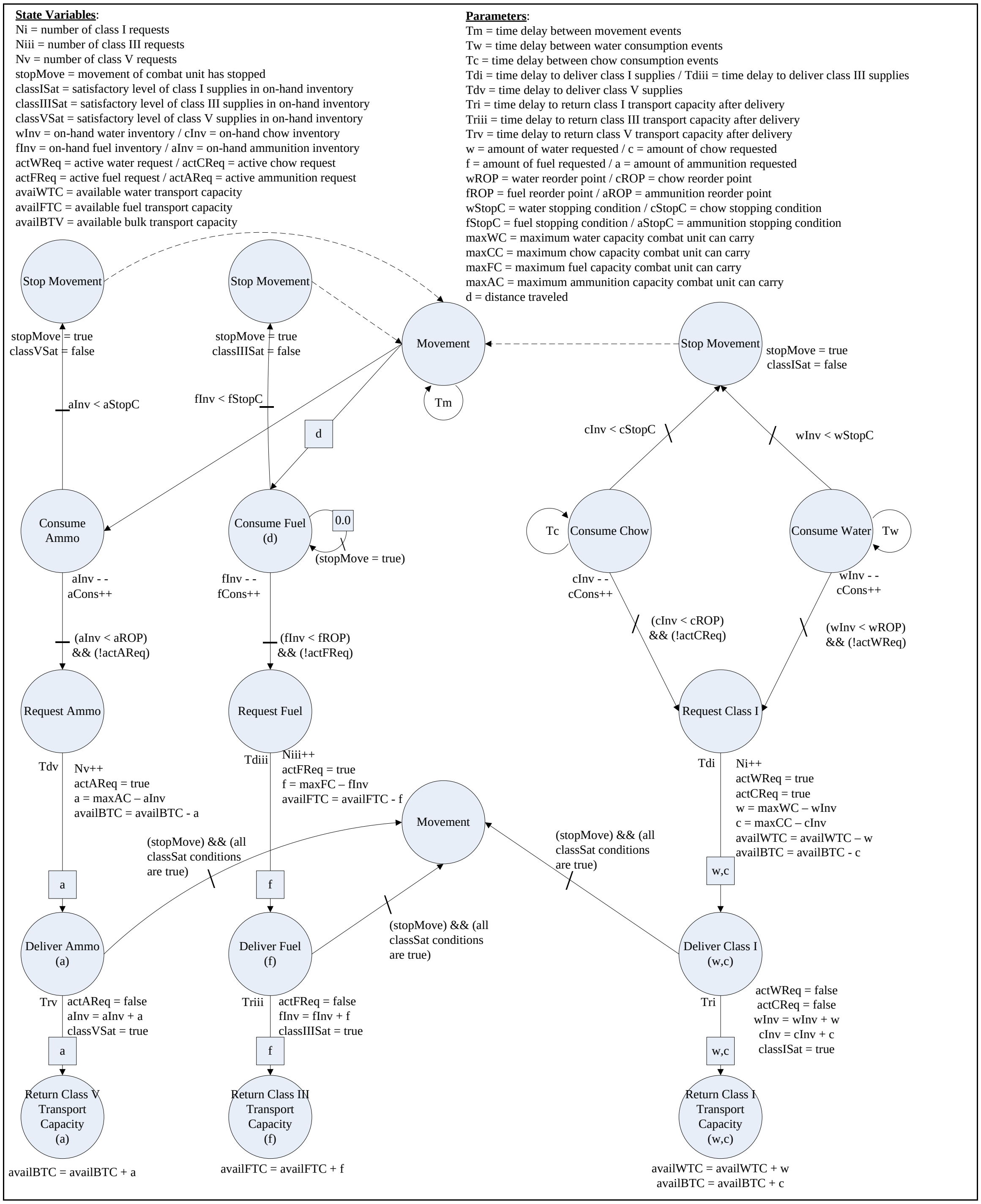

Figure 8. Logistics Process

THIS PAGE INTENTIONALLY LEFT BLANK

III. SCENARIO DESCRIPTION

This thesis evaluates the logistics process involving two combat units in the first fourteen days of an assault on four different objectives. The scenario and consumption rates are similar to the scenario outlined in the MAGTF Distribution Study with two exceptions. The manner in which logistics is provided to the task forces relies strictly on ground transportation from the supporting CSSE and a more current day MEB rather than a future 2015 MEB is assumed. The number of personnel and principle end items used in the scenario are similar but not exact to those used in the MAGTF Distribution Study. During the first two weeks of the assault it is assumed the direct distribution of resources to the GCE will be absorbed exclusively by ground transportation provided by the CSSE. Airlift capability resident in the MEB is assumed to be used for tactical support of the GCE and movement of logistics to the fixed location of the CSSE on shore. It is assumed it does not to contribute to the direct logistical support of the GCE.

A. SCENARIO AND TASK FORCE DATA

Each task force in the scenario has predetermined parameters at the beginning of the scenario. Each task force starts with a full capacity of class I and V supplies based on a days of supply amount in short-tons. Class III supplies are not determined by days of supply but by vehicle fuel tank capacity and additional fuel capacity carried by Mobile Combat Service Support Detachments attached to the GCE. Fuel inventory will also be measured in short-tons. Thus their initial inventory amounts are equivalent to their maximum capacity for these supplies. A reorder point based on a percentage of the maximum capacity is assigned for each class of supply within the task force. A movement rate and initial position is assigned to each task force as well.

1. Situation

The scenario starts at the conclusion of an amphibious landing in a hostile area of operations. A MEB sized force has conducted and completed the amphibious landings of two GCE task forces and one CSSE unit. Through the execution of maneuver warfare, each task force is assigned two geographical objectives to achieve within a fourteen day time span. The CSSE is responsible for sustaining the logistical capability of each task

force in order for them to reach their objectives. Air supremacy has been gained by the MEB prior to the amphibious landing, and the enemy is in a state of confusion and disorder due to the air strikes preceding the placement of the GCE onshore. With the confusion and disorder, the enemy's command and control capabilities have been rendered ineffective and the enemy is unable to execute a coordinated counteroffensive against the GCE and its supporting infrastructure. The enemy is able to organize into small defensive pockets and is immediately concerned with impeding each task force from achieving their desired objectives.

a. Friendly Forces and Equipment Composition

For this scenario Task Force One is comprised of 2700 personnel, 622 vehicles, and 211 pieces of engineering equipment. Task Force Two is comprised of 2150 personnel, 630 vehicles, and 108 pieces of engineering equipment. Table 1 on the following page lists the breakdown of vehicle and equipment types for each task force in more detail.

It is assumed there are enough skilled drivers and operators within each task force to employ all vehicles and pieces of equipment. There are no concerns for driver or operator availability. The travel rate for all vehicles throughout each task force is assumed to be constant from movement event to movement event. Therefore the movement of each task force will be conducted as one entity while moving toward their assigned objectives. Road networks and terrain are not considered in the scenario. A distance between the CSSE and the task forces is increasingly incremented as the task forces move toward their objectives and movement in the simulation will be executed in a straight line fashion away from the CSSE. This will represent the widening travel distance between each task force and the CSSE. It is assumed the distribution assets of the CSSE will employ the shortest route toward the task force when transporting supplies for the task force sustainment.

		TF 1	TF 2
PERSONNEL		2700	2150
EQUIPMENT			
TAMCN	Name Of Item		
A2075	RADIO SET, VEHICULAR	4	6
A2078	RADIO SET VEHICULAR	4	12
A2167	RADIO SET, VEHICULAR	40	64
A2168	RADIO SET, VEHICULAR	7	6
A2169	RADIO SET, VEHICULAR	12	20
	ATAMCN Totals	67	108
B0589	EXCAVATOR, ARMORED COMBAT (ACE)	24	16
B0730	GENERATOR SET, 3 KW, 60 HZ SKID-MTD	52	37
B0891	GENERATOR SET, 10KW, 60HZ, SKID-MTD	39	15
B0953	GENERATOR SET, 30KW, 60HZ, SKID-MTD, TACT QUIET	28	8
B1021	GENERATOR SET, 60KW, 60HZ, SKID-MTD	22	4
B2460	TRACTOR, FT, W/ANGLE BLADE	13	8
B2462	TRACTOR, MEDIUM, FULL TRACKED, TEREX	12	6
B2482	TRACTOR, ALL WHEEL DRIVE W/ATTACHMENTS	21	14
	BTAMCN Totals	211	108
D0198	MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR)	70	53
D1001	TRK AMB, 2 LITTER ARMD, 1 1/4 TON HMMWV	20	16
D1002	TRK AMB, 2 LITTER, SOFT TOP, 1 1/4 TON HMMWV	7	11
D1073	TRUCK, DUMP, 7T (MTVR)W/WINCH	34	20
D1125	TRUCK,UTILITY	23	22
D1158	TRK, UTILITY, CARGO TRP CARR 1 1/4 TON W/EQUIP, HM	211	247
D1159	TRK, UTILITY, ARMT CARR W/SA 1 1/4 TON W/EQUIP HMM	54	55
D1161	INTERIM FAST ATTACK VEHICLE (IFAV)	23	22
	DTAMCN Totals	442	446
E0856	ASSAULT AMPHIBIOUS VEHICLE, RECOVERY	1	1
E0857	ASSAULT AMPHIBIOUS VEHICLE	25	25
E0942	LAV ANTI-TANK	8	8
E0946	LAV COMMAND AND CONTROL (BN)	2	2
E0947	LIGHT ARMORED VEHICLE	28	28
E0948	LAV, LOGISTICS	6	6
E0949	LIGHT ARMORED VEHICLE MORTAR CARRIER	4	4
E0950	LAV MAINTENANCE/RECOVERY	2	2
E0996	MAIN BATTLE TANK (MBT) TRACK WIDTH MINE PLOW	8	0
E1378	RECOVERY VEHICLE, FULL TRACKED, MEDIUM, W/E	1	0
E1888	TANK, COMBAT, FT, 120MM GUN	28	0
	ETAMCN Totals	113	76

Table 1. Total Task Force Personnel and Major Equipment

b. Enemy Forces

The explicit introduction and composition of an enemy force is not required in the scenario. The consumption of ammunition at a given rate makes it apparent there is an enemy that is resisting the advance of each task force and the direct and indirect fire of the GCE is directed toward the enemy. Thus, the effects of the enemy force on the CSSE are captured in the model. It is assumed each task force will reach their assigned objectives and the enemy will abandon their defensive positions as the task

force advances. It is further assumed that the enemy is incapable of mounting a counter offensive or conducting coordinated attacks on the logistics infrastructure of the MEB due an ineffective command and control structure. This greatly diminishes the chance of an event occurring where a task force is met with a sizeable enemy resistance that would force the expenditure of large amounts of ammunition.

2. Logistics

The first fourteen days of the assault employs a simple logistics plan for the MEB. The MEB has established a sea-based platform to distribute logistics ashore. The majority of air assets are employed for tactical purposes during the assault phase. Any remaining air assets are used to complement shipping assets focused on the transportation of logistic supplies to elements of the CSSE that have gone ashore. It is assumed there are enough logistical supplies aboard MEB shipping to sustain the movement of the GCE. It is also assumed that the CSSE ashore is never short of any class of supply that may be required by the GCE.

a. Logistics Distribution between CSSE and GCE

Some of the principles of logistics were introduced in the first chapter of this thesis. Due to the high operational tempo employed in maneuver warfare the logistics plan between the CSSE and the GCE will seek to apply and maintain the principles of logistics. Simplicity in the logistics plan is paramount in order to avoid confusion and resist becoming disorganized during maneuver warfare. The CSSE of the MEB will have two detachments formed for the purpose of supplying distribution capacity and supporting the GCE of the MEB. One will be a general support detachment and the other a direct support detachment. The single general support detachment will be responsible for supporting both task forces. The direct support detachment will form an additional two detachments and assign each to an individual task force. These smaller detachments will be attached to each task force and each will be termed a Mobile Combat Service Support Detachment (MCSSD). An MCSSD will follow their assigned task force toward its objective and allow each task force to have immediate access to logistics resources as they are consumed. An MCSSD basically expands the logistics inventory capacity for the assigned task force. For the purpose of this study it expands the inventory capacity of each task force in respect to the class I, III, and V types of supplies.

An MCSSD allows the combat and firepower assets of the task force to conduct maneuver warfare without being burdened by an internal logistics load. Figure 9 illustrates the manner in which supplies will be requested and distributed in this scenario.

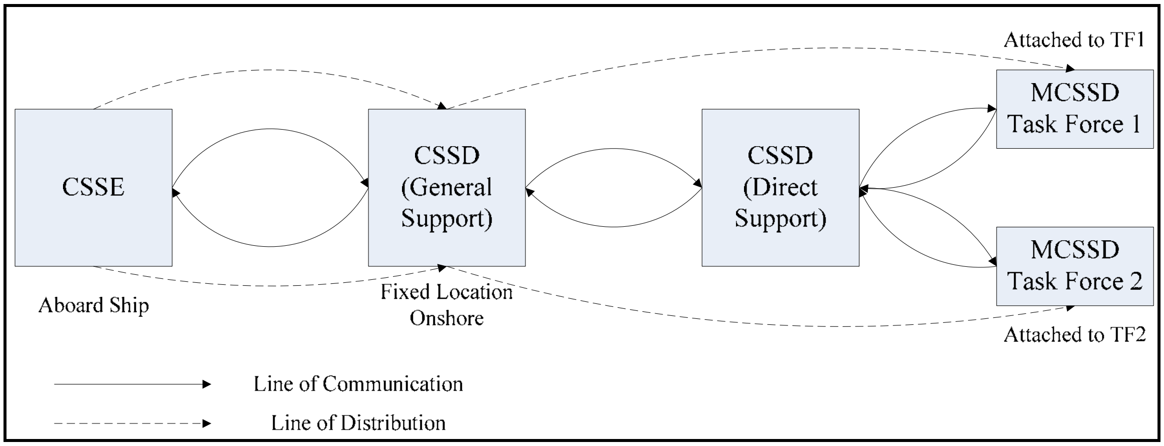

Figure 9. Scenario Distribution Network

b. TCL Model Roles and Request Process

Within a logistics distribution network the TCL Model has identified roles which are necessary to complete specific logistics tasks. We now introduce these roles and their responsibilities within the distribution network as defined by the TCL Model. Defining these roles will assist in understanding the process and actions in which supplies are requested by the GCE and delivered by the CSSE within the scenario. Within the MAGTF there are a variety of billet titles and descriptions that cover these responsibilities. Because of this these roles are termed generically within the TCL Model in order to capture a variety of billets that perform the same function. We next identify these billets and roles as defined by the TCL Model (Decision Engineering, 2004).

(1) Distribution Capacity Management (DCM): An operational role within Distribution that plans, prioritizes, and optimizes capacity within the domain of Distribution. The primary responsibilities of this role are to allocate capacity and capability to orders and to maintain visibility and to report status of capacity and capability within that domain.

(2) Distribution Executer (DE): An operational element within Distribution that executes tasks within the domain of Distribution to fulfill orders and reports execution status.

(3) Distribution Production Management (DPM): An operational role within Distribution that plans and controls execution within Distribution. The primary responsibilities of this role are to apply capability and capacity to orders, to maintain visibility of execution status, and to report the status of resources within Distribution.

(4) Inventory Capacity Management (ICM): An operational role within Inventory that plans, prioritizes, and optimizes capacity with the domain of Inventory. The primary responsibilities of this role are to allocate capacity and capability to orders and to maintain visibility and to report status of capacity and capability within that domain.

(5) Inventory Executer (IE): An operational element with Inventory that executes tasks within the domain of Inventory to fulfill orders and reports execution status.

(6) Order Management (OM): An operational element or role that serves as the supported unit's primary advocate. The primary responsibilities of this role are to manage customer orders from start to completion, to communicate order status externally and order requirements internally, and to coordinate other requirements with capacities and capabilities of other operational elements.

(7) Request Management (RM): An operational role that receives requirements from supported units and translates requirements into a request to be submitted to order management.

The TCL Model has identified a number of logistics processes. Within these processes there are a variety of logistics tasks that make up the whole of any given process. Each individual task requires a certain amount of time to complete. The amount of time to complete this task is modeled as a random variable having a triangle distribution with three parameters. The first parameter is the shortest or most optimistic amount of time in which a logistics task may be completed. Essentially, if everything goes correctly the task will be completed in this amount of time. The second parameter is

the most likely amount of time the logistics task will be performed. The third parameter is the longest or most pessimistic amount of time the logistics task may be completed. Thus, the shortest time is what is given if everything goes right, the longest time is given if everything goes wrong. The time to complete any given logistics task lies somewhere within these three parameters.

For this scenario we focus on the process of fulfilling a requested product. Using the defined terms above we describe the tasks that are necessary to complete this logistics process defined by the TCL Model. A table of the process with each tasks time parameters can be found in Appendix B. The first step in the request process is the generation of a request by the RM for a product via the OM. The OM creates a customer order and checks with the ICM to ensure the product is available within the general support inventory. The OM also checks with the DCM to ensure appropriate distribution assets are available to transport the product to the RM. The OM will assess the capability of both the ICM and the DCM to deliver the product within the conditions of the request and will reconcile with the RM the conditions of the request and the time window and location of delivery. The DCM and the ICM will then coordinate between them a pickup of the product in order to meet the delivery requirements. Once that is done, the DPM will task the appropriate DE for distribution of the product, while the IE will pack and stage the product for the DE. The DE will then receive the requested product from the IE and load it onto the appropriate transportation asset. The DE then transports the product to the location of the RM. Once there the RM will receive the requested product and the request will be fulfilled. (TCL Model, 2004)

For the purposes of the scenario the RM will be located with the MCSSD or the CSSD for direct support. The OM will be located with the CSSD for general support. All distribution and inventory roles will be located with the CSSD for general support. Supplies will be distributed to the general support CSSD from the CSSE located aboard the sea based logistics platform. Again, it is assumed the general support CSSD will never be diminished in any type of supply required by the task forces. Therefore, all class I, III, and V supplies are considered to be stocked within the general support CSSD. The DE for the scenario will deliver all requested products from the general support CSSD straight to the MCSSD for each task force. When the product is

delivered to the MCSSD it will be considered received by the task force and the inventory for the delivered product will increase by the requested amount. The location for delivery to the requesting task force will be the geographical point the task force entity was located when it made the request. Time for processing a request is determined by the logistics process for fulfilling a product order in the TCL Model and the rate at which the DE travels. For this scenario the DE will travel at a constant speed of 15 mph when transporting supplies from the general support CSSD location to the MCSSD.

c. Distributions and Consumption Rates for Task Forces

The amount of consumption for individual classes of supply can be considered to be a random variable. The MDC study identified daily rates of consumption for each class of supply but left the rate as a constant from day to day. With this in mind triangle distributions are used to simulate a random amount of consumption for those supplies whose measurement of consumption is continuous from consumption event to consumption event. A triangle distribution is the result of a heuristic procedure in the absence of data (Law and Kelton, 2005). For the consumption of water, fuel, and ammunition intervals will be established in which it is felt the probability of the amounts of supplies consumed lying within these intervals is close to one. The most likely value for these intervals will be represented by the consumption rate constants displayed in the MDC study.

d. Water Capacity and Consumption Parameters for Task Force

We now detail the water capacity and consumption for each task force in the scenario. All capacities, inventories, and consumption rates within the scenario will be expressed in short tons. The amount of water consumption will be figured as a whole for each task force. This scenario will use the most likely water consumption rate of 4.07 gallons per person per day defined in the MDC Study. To convert the weight of water to short-tons we will assume the conversion of one gallon of water being equal to 8.35 pounds. Water consumption for a task force is figured as the product of the number of personnel in a task force and the water consumption rate of 4.07 gallons per day. That product is then converted to pounds and then into short tons consumed by a task force each day. Finally, a water consumption event occurs every one simulated hour. The resulting quotient of dividing the short tons consumed by a 24-hour period indicates the

amount of water consumed by a task force during each consumption event. Table 2 exhibits the water consumption of each task force. The final interval for the triangle distribution for water consumption in short tons is (1.412, 2.412) for task force one and (1.022, 2.022) for task force two.

WATER CONSUMPTION RATE		
1 Gallon Water = 8.35 lbs		
	TF 1	TF 2
Personnel	2700	2150
Consumption Rate		
Most likely # gallons per person per day	4.07	4.07
# lbs per person per day	33.9845	33.9845
# lbs per Task Force per day	91758.15	73066.675
# Short Tons per Task Force per day	45.879075	36.5333375
Most likely # Short Tons per Consumption Event	**1.911628125**	**1.522222396**

Table 2. Water Consumption Rate by Task Force

The water capacity carried by each task force is measured in days of supply in short-tons. It is constructed by taking the most likely water consumption rate and multiplying it by the number of personnel in each task force to get the estimated required days of supply for water in gallons for each task force. A conversion using the one gallon of water being approximately equal to 8.35 lbs is made and we arrive at the final estimated result for one day of supply of water for each task force in short-tons. Each MCSSD allows an expansion in the inventory capacity for each assigned task force. Extra days of supply will be carried by the MCSSD to complement the task forces they drive toward their assigned objectives. For this scenario the principle end items will consist of fabric drums, SIXCONs, and water trailers. Table 3 and Table 4 on the following page exhibit a total personnel and possible principle end items that result in a possible maximum water capacity that can be carried by each of the task forces.

WATER CAPACITY FOR TF PERSONNEL		
1 Gallon = 8.35 lbs		
	TF 1	TF 2
Personnel	2700	2150
Daily rate in gallons	4.07	4.07
Required DOS in gallons	10989	8750.5
Required DOS in lbs	91758.2	73062.5
Capacity per TF personnel in DOS Short-Tons	**45.8791**	**36.5313**

Table 3. Water Capacity of Task Force Personnel

MCSSD WATER CAPACITY FOR TF	Gallon Capacity	Short Ton Capacity	# TF 1	Short Tons TF 1	# TF 2	Short Tons TF 2
1 Gallon = 8.35 lbs TAMCN (Description)						
B0571 (Drum Fabric Water, 500 Gallon)	500	2.0875	10	20.8750	8	16.7000
B2086 (Storage Tank Module (SIXCON))	900	3.7575	18	67.6350	21	78.9075
D0880 (Trailer, Tank, Water, 400 Gallon)	400	1.67	10	16.7000	2	3.3400
	TF 1	TF 2				
MCSSD Water Capacity in Short Tons	105.2100	98.9475				
Possible Capacity carried by TF personnel in Short Tons	22.5450	17.9525				
Total TF Water Capacity in Short Tons	**127.7550**	**116.9000**				

Table 4. Total Water Capacity of Task Forces

In this table it is assumed that personnel are carrying two gallons of water on their persons. Adding to that the possible water capacity an MCSSD and for this scenario we can conclude the task forces are carrying approximately three days of supply in water short-tons. For simplicity, when running the simulation the task forces will be considered to carry a whole amount of days of supply.

e. Chow Capacity and Consumption Parameters for Task Force

Like water consumption, the amount of chow consumption will be figured as a whole for each task force and is dependent on the number of personnel within each task force. Unlike water, fuel, and ammunition it will be assumed that chow consumption is relatively constant. This thesis will use the chow consumption rate of three meals per day or one meal per chow consumption event. It is assumed that one meal is equivalent to one pound in weight. Chow consumption for a task force is figured as the product of the number of personnel in a task force and the chow consumption rate

one pound per consumption event. That product is then converted into short tons consumed by a task force for each consumption event. This yields a chow consumption rate of 1.35 short tons for task force one and 1.075 short tons for task force two. A chow consumption event occurs every eight simulated hours. Table 5 displays the data for chow consumption within the scenario.

CHOW CONSUMPTION RATE		
1 Meal = 1 lbs		
	TF 1	TF 2
Personnel	2700	2150
Consumption Rate		
# lbs per meal	1	1
# lbs per Consumption Event	2700	2150
# Short Tons per Consumption Event	**1.35**	**1.075**

Table 5. Chow Consumption Rate by Task Force

The chow capacity carried by each task force will be determined by the number of days of supply. We assume that each person in the task force has the capacity to carry three meals on their immediate person for one full day of supply. We also assume that each MCSSD is capable of carrying up to an additional three days worth of meals per person for their assigned task force in this scenario. Therefore there is a capacity to carry up to four days worth of supply per person in each task force. Table 6 demonstrates the chow capacity for each task force.

CHOW CAPACITY FOR TF PERSONNEL		
1 Meal = 1 lbs	TF 1	TF 2
Personnel	2700	2150
Capacity per person in lbs	3	3
Capacity per TF personnel in lbs	8100	6450
Capacity per TF personnel in Short Tons	4.05	3.225
MCSSD CHOW CAPACITY FOR TF		
MCSSD # meals per person in lbs	9	9
MCSSD Capacity per TF personnel in lbs	24300	19350
MCSSD Capacity per TF personnel in Short Tons	12.15	9.675
Total Chow Capacity in Short Tons per Task Force	**24.30**	**19.35**

Table 6. Total Chow Capacity of Task Forces

f. Fuel Capacity and Consumption Parameters for Task Force

Fuel capacity and consumption for each task force in the scenario depends on the amount of vehicles and equipment that are employed by each task force and the distance traveled during movement. All capacities, inventories, and consumption rates of fuel within the scenario will be expressed in short tons. The amount of fuel consumption will be figured as a whole for each task force. This thesis will use a fuel consumption rate based on the amount and types of vehicles and equipment in each task force. Since each task force's vehicle and equipment composition varies, it is only reasonable to assume the rate at which they consume fuel will also vary. An aggregated fuel consumption rate will be used to determine the fuel consumption rate for each task force. The consumption of fuel by vehicles and engineer equipment will be handled separately. Finally, we assume the conversion of one gallon of diesel being approximately 7.1 pounds.

The MDC Study bases fuel consumption by vehicles as an hourly rate. Since the defined logistics process model developed in chapter two consumes fuel based

on movement, we must dispatch the idea of fuel being consumed at an hourly rate and derive a standard consumption of fuel for vehicles based on distance traveled. Each type of vehicle burns fuel based on a mile per gallon ratio. However not all fuel consumption ratios are equivalent. A HMMWV variant has a 14 mile per gallon ratio while an M1A1 Battle Tank has a ratio that is less than one. To compose an overall mile per gallon ratio for each task force we figure the amount of gallons each vehicle type would consume if they traveled 250 miles, a distance that is within the maximum range of all vehicle types given a fuel tank that is filled to capacity. We then take the product of gallons consumed by each vehicle type and the number of vehicles for each type within a task force to arrive at the total gallons consumed by that type of vehicle. The equation follows here for each type of vehicle:

(Vehicle Type MPG/250 Miles)*(# vehicles) = Total Gallons Consumed

Once each vehicle type has a total amount of gallons consumed we sum all of them together to arrive at the total number of gallons consumed by the task force. If we multiply the number of vehicles in each task force by 250 miles we get the total distance in miles traveled by all the vehicles in the task force. We then take the total number of miles traveled and divide it by the number of total gallons consumed to arrive at an overall aggregated mile per gallon rate for a task force. Table 7 displays the overall mile per gallon ratio for task force one.

Vehicles	**MPG**	**# TF 1**	**Gallons Consumed over 250 miles**			
7-Ton	4.5	104	5777.777778			
HMMWV Variants	14	382	6821.428571			
IFAV	11.2	23	513.3928571			
LAV	5.125	50	2439.02439			
AAV	1.754	26	3705.815279			
Tanks	0.595238	37	15540.00249			
		622	34797.44136			
				Optimistic	Likely	Pessimistic
Total Miles by TF	155500		Gallons Consumed per Mile per Vehicle	0.223777758	0.319682511	0.447555516
Optimistic MPG	4.46871936		Lbs Consumed per Mile per Vehicle	1.588822081	2.269745831	3.177644163
Likely MPG (70%)	3.12810355		Lbs Consumed per Mile per TF	988.2473347	1411.781907	1976.494669
Pessimistic MPG (50%)	2.23435968		**S-Tons Consumed per Mile per TF**	**0.494123667**	**0.705890953**	**0.9882473**

Table 7. Task Force One Vehicle Fuel Consumption Rates

Taking note of the rates in short tons consumed per mile per task force in the bottom right cells, we see there are three fuel consumption rates for a triangular distribution. The mile per gallon ratio we derived in the preceding paragraph is based on the cruising speeds of all the vehicle types. In other words the scenario assumes that the vehicles are operating in a state that promotes their most efficient fuel consumption. During maneuver warfare it is extremely unlikely (although possible) that all vehicles will consume fuel at their most efficient rate while moving toward their objectives. Therefore the mile per gallon ratio just derived will be the optimistic measurement. With maneuver warfare it is most likely there will be starting and stopping of vehicles and heavy acceleration. There will be instances vehicles will reach a cruising speed but it is unlikely to remain constant. And there will be times when vehicles may have to travel parallel to their objectives, travel through rough terrain, ascend steep slopes, etc. All of these situations are examples when vehicles are not operating in their most fuel efficient state. It will be assumed vehicles in each task force, as a whole for this scenario, will most likely consume fuel at a rate that is 70% of their most efficient aggregated rate during any given movement event. Finally, it will be assumed that vehicles in the task force will do no worse than consuming fuel as a whole at 50% the task force's most efficient aggregate rate during any given movement event. The fuel consumption rate for task force two vehicles is displayed in Table 8.

The MDC Study defines fuel consumption by engineer equipment as an hourly consumed rate of six gallons per hour for 16 hours a day. This thesis will adopt the idea of fuel being consumed by engineer equipment and use the parameter that engineer equipment is operated for 16 hours a day. The rate at which fuel is consumed will be determined by the amount of gallons each individual piece of engineer equipment consumes per hour. To determine the amount of fuel consumed by engineer equipment in a task force we find the gallons of fuel consumed per hour for each type. We multiply this rate by the number of pieces of equipment for each type within the task force. We then sum up all the products to arrive at the total fuel consumed by a task force each hour. After converting the rate to short tons we find the amount of short tons burned in a sixteen hour time period. Since the simulation is based on a 24-hour day we adjust the

previous rate to be equivalent to a 24-hour time period. Table 9 shows the fuel consumption rate of engineer equipment for task force one.

Vehicles	MPG	# TF 2	Gallons Consumed over 250 miles			
7-Ton	4.5	73	4055.555556			
HMMWV Variants	14	459	8196.428571			
IFAV	11.2	22	491.0714286			
LAV	5.125	50	2439.02439			
AAV	1.754	26	3705.815279			
Tanks	0.595238	0	0			
		630	18887.89523			
				Optimistic	Likely	Pessimistic
Total Miles by TF	157500		Gallons Consumed per Mile per Vehicle	0.119923144	0.171318778	0.239846289
Optimistic MPG	8.33867396		Lbs Consumed per Mile per Vehicle	0.851454324	1.216363321	1.702908649
Likely MPG (70%)	5.83707177		Lbs Consumed per Mile per TF	536.4162244	766.308892	1072.832449
Pessimistic MPG (50%)	4.16933698		**S-Tons Consumed per Mile per TF**	**0.268208112**	**0.383154446**	**0.5364162**

Table 8. Task Force Two Vehicle Fuel Consumption Rates

Engineer Equipment	Gals/Hr	#TF 1	TF1 Gal/Hr
ACE	6.9	24	165.6
B0730 Generator	0.5	52	26
B0981 Generator	3	39	117
B0953 Generator	2.9	28	81.2
B1021 Generator	6	22	132
B2460	6	13	78
B2462	6	12	72
B2482	4	21	84
			755.8
Lbs per Hour per TF			5366.18
S-Tons per Hour per TF			2.68309
S-Tons per 16-Hr per TF			42.92944
S-Tons per 24 Sim Hrs per TF			1.788726667
S-Tons per Sim Movement per TF			**0.178872667**

Table 9. Task Force One Engineer Equipment Fuel Consumption Rate

Engineer equipment is relatively stationary when operating. Therefore we do not attempt to define an optimistic, likely, and pessimistic rates in which engineer equipment operate. Table 10 displays the consumption rate of engineer equipment within task force two. Of note will be the frequency in which the fuel is burned by engineer equipment. To link the consumption of fuel by vehicles (which is based on distance) and

the consumption of fuel by engineer equipment (which is based on time) we tied overall fuel consumption to the movement event. In the logistics process model the movement event is scheduled every .1 simulation hours. Each task force will move a given distance based on their movement rate and that distance will assist in determining the amount of fuel consumed by vehicles. Engineer equipment will consume a tenth of the amount of fuel they would consume in a full hour. Thus the given rate for engineer equipment is based on the simulated movement event.

Engineer Equipment	Gals/Hr	# TF 2	TF2 Gal/Hr
ACE	6.9	16	110.4
B0730 Generator	0.5	37	18.5
B0981 Generator	3	15	45
B0953 Generator	2.9	8	23.2
B1021 Generator	6	4	24
B2460	6	8	48
B2462	6	6	36
B2482	4	14	56
			361.1
Lbs per Hour per TF			2563.81
S-Tons per Hour per TF			1.281905
S-Tons per 16-Hr per TF			20.51048
S-Tons per Sim Hr per TF			0.854603333
S-Tons per Sim Movement per TF			**0.085460333**

Table 10. Task Force Two Engineer Equipment Fuel Consumption Rate

Fuel capacity for each task force is determined by the vehicle and engineer equipment's fuel tank capacity. The amount of supporting capacity carried by the assigned MCSSD also contributes to the overall fuel capacity carried within a task force. Table 11 and Table 12 on the following pages display the fuel capacities for each task force. The total fuel capacity is arrived at by taking the fuel tank capacity in gallons for each vehicle, engineer equipment, and MCSSD supporting equipment and multiplying that by the conversion rate of 7.1 pounds. The fuel tank capacity in pounds is then converted to short tons. Finally, the amount of short tons each type of vehicle and equipment can carry is multiplied by the number resident within each task force. The products are then summed together to reach the overall fuel capacity carried by each task force.

Vehicles	Gallon Tank Cap	Lbs Tank Cap	S-Ton Tank Cap	# TF1	TF1 S-Ton Tank Capacity
7-Ton	80	568.0	0.2840	104	29.5360
HMMWV Variants	25	177.5	0.0888	382	33.9025
IFAV	25	177.5	0.0888	23	2.0413
LAV	80	568.0	0.2840	50	14.2000
AAV	171	1214.1	0.6071	26	15.7833
Tanks	504	3578.4	1.7892	37	66.2004
Vehicle Fuel Capacity in S-Tons					**161.6635**
Engineer Equipment					
ACE	132	937.2	0.4686	24	11.2464
B0730 Generator	4.8	34.1	0.0170	52	0.8861
B0981 Generator	12.5	88.8	0.0444	39	1.7306
B0953 Generator	25	177.5	0.0888	28	2.4850
B1021 Generator	55	390.5	0.1953	22	4.2955
B2460	120	852.0	0.4260	13	5.5380
B2462	120	852.0	0.4260	12	5.1120
B2482	24	170.4	0.0852	21	1.7892
Engineer Equip Fuel Capacity in S-Tons					**33.0828**
MCSSD Supporting Equipment					
B0570 500 Gallon Fabric Drum	500	3550.0	1.7750	19	33.7250
B2085 Sixcon (Fuel)	900	6390.0	3.1950	12	38.3400
MCSSD Equip Fuel Capacity in S-Tons					**72.0650**
Total TF Fuel Capacity					**266.8113**

Table 11. Total Fuel Capacity for Task Force One

Vehicles	Gallon Tank Cap	Lbs Tank Cap	S-Ton Tank Cap	#TF2	TF2 S-Ton Tank Capacity
7-Ton	80	568.0	0.2840	73	20.732
HMMWV Variants	25	177.5	0.0888	459	40.73625
IFAV	25	177.5	0.0888	22	1.9525
LAV	80	568.0	0.2840	50	14.2
AAV	171	1214.1	0.6071	26	15.7833
Tanks	504	3578.4	1.7892	0	0
Vehicle Fuel Capacity in S-Tons					**93.40405**
Engineer Equipment					
ACE	132	937.2	0.4686	16	7.4976
B0730 Generator	4.8	34.1	0.0170	37	0.63048
B0981 Generator	12.5	88.8	0.0444	15	0.665625
B0953 Generator	25	177.5	0.0888	8	0.71
B1021 Generator	55	390.5	0.1953	4	0.781
B2460	120	852.0	0.4260	8	3.408
B2462	120	852.0	0.4260	6	2.556
B2482	24	170.4	0.0852	14	1.1928
Engineer Equip Fuel Capacity in S-Tons					**17.4415**
MCSSD Supporting Equipment					
B0570 500 Gallon Fabric Drum	500	3550.0	1.7750	0	0
B2085 Sixcon (Fuel)	900	6390.0	3.1950	18	57.51
MCSSD Equip Fuel Capacity in S-Tons					**57.5100**
Total TF Fuel Capacity					**168.3556**

Table 12. Total Fuel Capacity for Task Force Two

g. Ammunition Capacity and Consumption Parameters for Task Force

Ammunition capacity and consumption for each task force in the scenario is dependent on the number of personnel in each task force. All ammunition capacities, inventories, and consumption rates within the scenario are expressed in short tons. The amount of ammunition consumption is figured as a whole for each task force. This thesis will use the ammunition consumption rates used in the MDC Study as the most likely rate. The total consumption rate is split into two categories in the MDC Study. There is a consumption rate for small arms and a consumption rate for artillery rounds. The consumption rate for small arms ammunition is defined as 6.5 lbs per man per day. The consumption rate for artillery ammunition is 23.5 lbs per man per day. This makes a total most likely rate of 30 lbs of ammunition per man per day. Table 13 demonstrates the

ammunition consumption rates for both task forces in short tons and expresses the amount of ammunition consumed each movement event.

AMMUNITION CONSUMPTION RATES		
Most likely Small Arms = 6.5 lbs/man/day **Most likely Artillery = 23.5 lbs/man/day**		
	TF 1	TF 2
Personnel	2700	2150
Consumption Rate		
Most likely Small Arms per man per day	6.5	6.5
Most Likely Artillery per man per day	23.5	23.5
# Lbs per man per day	30	30
# Lbs per TF per day	81000	64500
# Short Tons per TF per day	40.5	32.25
# Short Tons per TF per Hour	1.6875	1.34375
Most Likely # Short Tons per TF per Simulation Movement	**0.16875**	**0.134375**

Table 13. Ammunition Consumption by Task Force

The triangle distribution interval for ammunition consumption by each task force in pounds per man per day is (23.5, 37.5). This translates to task force one's interval consumption being (0.13219, .21094) in short-tons per simulation movement. Task force two's interval consumption is (.10526, .16798) in short-tons per simulation movement.

The ammunition capacity carried by each task force will be determined by the number of days of supply carried within the task force. We assume that each person in the task force has the capacity to carry one day of supply in small arms ammunition on their immediate person. We also assume there is up to three additional days of supply carried by each MCSSD. Therefore each task force is capable of carrying up four days worth of small arms ammunition per person for their assigned task force in this scenario.

Artillery ammunition will be handled in the same way and we can expect up to four days worth of artillery ammunition carried by each task force. Table 14 depicts the ammunition capacity carried by each task force

AMMUNITION CAPACITY FOR TF PERSONNEL		
Small Arms = 6.5 lbs/man/day **Artillery = 23.5 lbs/man/day**		
	TF 1	TF 2
Personnel	2700	2150
Small Arms Capacity per person in lbs	6.5	6.5
Artillery Capacity per person in lbs	23.5	23.5
Capacity per TF personnel in DOS Short Tons	40.5	32.25
MCSSD AMMUNITION CAPACITY FOR TF		
Max DOS Small Arms Capacity per person in lbs	19.5	19.5
Artillery Capacity per person in lbs	70.5	70.5
MCSSD Capacity per TF personnel in DOS Short Tons	95.175	75.7875
Max Total DOS Ammunition Capacity in Short Tons per Task Force	**135.675**	**108.038**

Table 14. Total Ammunition Capacity by Task Force

h. Movement Rates for Task Forces

The movement rate for each task force per movement event will be based on a triangular distribution. It is assumed the interval of the distribution will be (18.0, 35.0) in terms of miles per day with the most likely rate being 25.0 miles per day. This translates to an interval of (.75, 1.45833) per movement event with 1.04167 miles being the most likely value per movement event.

i. Assigned Objectives for Task Forces and Definition of Successful Sustainment

Each task force will have two assigned objectives. The first objective will be 150 miles away from the CSSE position and the second objective will be 250 miles away from the CSSE position. The GCE as a whole will not be considered to have reached its objectives until both task forces have reached their two assigned objectives. The GCE reaching all of its assigned objectives within a fourteen day time frame (336.0 simulation hours) will be defined as a successful sustainment. Any time required to reach the overall GCE objective that exceeds the fourteen day time frame will be seen as a failure in sustainment.

B. COMBAT SERVICE SUPPORT DATA

The CSSE unit engaged in a general support role and responsible for sustaining the movement of each task force will have predetermined characteristics assigned. An initial location will be assigned and remained fixed throughout the duration of the scenario. A movement rate of 15 miles per hour will be assumed to determine the time delay for delivery of supplies from the detachment's position to either task force position. One of the factors of interest in this thesis is the transportation capacity resident within the CSSE that is dedicated to the movement of supplies to each task force. Maximum transport capacities will be assigned for water, fuel, and bulk cargo. The transportation capacities resident in the CSSE will be figured based on a percentage of the total days of supply carried by the GCE. Therefore, if the GCE is carrying four days of supply for all inventories and the transportation capacity for the CSSE is deemed to be 100% the dedicated transportation capacity for movement of supplies will be four days of supply for the whole GCE.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. RESULTS AND ANALYSIS

This chapter presents the results obtained from running the simulation and the following analysis. The analysis will focus on answering the question of what factors are considered significant and which combination of factors prove to be the most efficient and successful in sustaining the GCE. All combinations of the simulation scenario are executed on an Intel ® Pentium® 4 CPU, 2.40 GHz computer with 512 MB of RAM running under Microsoft Windows XP operating system. The simulation is coded in the Java programming language using the Simkit DES library. The analysis of the results was completed with JMP 5.1 statistical software developed by the SAS Institute.

A. EXPERIMENTAL DESIGN

As stated in chapter one, there are three factors of interest: days of supply carried by the GCE, the reorder point for on-hand inventory, and the transportation capacity resident within the CSSE. The days of supply factor will have three levels and simulations will be run using values of two, three, and four days of supply carried by the GCE. The reorder point factor will have four levels and simulations will be run using values of .3, .4, .5, and .6 of the initial maximum on-hand inventories carried by the GCE. The initial transportation capacity resident within the CSSE will be determined as a fraction of the initial maximum on-hand inventories of the GCE. Transportation capacity will have three levels and simulations will be run using values of .5, .75, and 1.0 for the factor.

A full factorial design will be employed in the simulation. With three factors and respective levels of three, four, and three we have a possibility of thirty-six different combinations. Thirty replications will be run for each of the combinations to result in a total of 1080 simulation runs.

B. RESULTS OUTPUT

The tables in Appendix C list the results of each simulation run with the associated fixed factors and their levels. There are three factors considered. The first

factor is maximum days of supply (DOS) the GCE task forces are capable of carrying. Only class I and class V DOS was varied from simulation run to simulation run. Class III supplies remained fixed throughout each simulation run. The second factor is the reorder point (ROP) level the GCE task forces will wait to reach before requesting more supplies. The last factor is the maximum transportation capacity (TC) the CSSE has available to allocate toward moving requested supplies to the respective GCE task forces. The CSSE transportation capacity is varied as a percentage of the total DOS capacity the GCE task forces are capable of carrying for all supply classes.

There are three data tables of output. Each table represents one of three levels for the DOS factor. Within each table there are an additional two factors listed. There are four levels for the ROP factor and three levels for the transportation capacity factor (labeled TC). This yields twelve columns per table in order to capture each combination of factors and there given levels. The cells in each table represent the time required for the GCE to achieve its overall objective. Cells containing values that exceed 336.0 hours indicate the GCE failed to reach the required objectives within the fourteen day time frame allowed for the assault; the CSSE was unable to sustain the movement of the GCE given the fixed values of that simulation run. The percentages at the bottom of each column of the tables represent the success rate the GCE achieved its objectives within the allotted time frame. With this data we look to study the measures of effectiveness and goals stated in chapter one.

C. LOGISTIC REGRESSION FOR SUCCESS

The first measure of effectiveness analyzed is whether the three factors are significant in determining the success of the GCE. This is accomplished by fitting a logistic regression model to the data and using the negative log-likelihood to compute a likelihood ratio chi-square test. Logistic regression is a method to estimate the probability of choosing one of the response levels as a smooth function of the factors (Sall, Creighton, Lehman, 2005). We use the data from Appendix C. A binary response is created to represent success and failure in relation to the amount of time required to accomplish the mission. The cells containing values greater than 336.0 hours are converted to “0” to correspond to a failure and indicate the GCE took longer than

fourteen days to reach their objectives. Cells containing values that are less than or equal to 336.0 are converted to "1" to correspond to a success and indicate the GCE reached all their objectives within a fourteen day period. Using the JMP software we enter the data with the response variables as ordinal types and the predictor variables as continuous types. A histogram, mosaic plot, and frequency table of the response variable data is shown below.

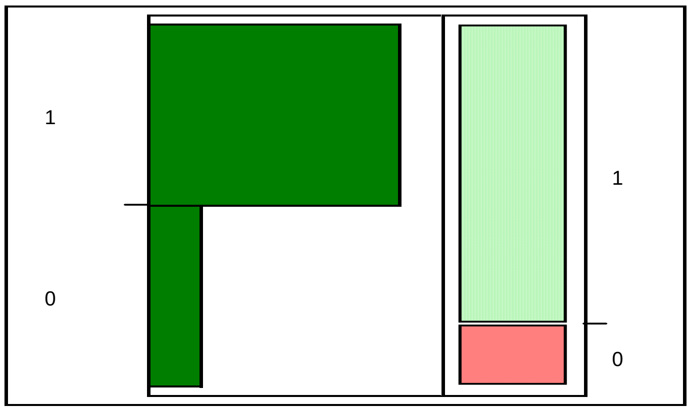

Figure 10. Histogram and Mosaic Plot of Success Rates

Level	Count	Probability	Lower CI	Upper CI	1-Alpha
0	189	0.17500	0.153502	0.198802	0.950
1	891	0.82500	0.801198	0.846498	
Total	1080	1.00000			

Table 15. Frequency Table of Sustainment Success Rates

After 1080 simulation runs, the overall success rate is 82.5% with a 95% confidence interval of (80.1%, 84.6%) for all combinations of all three factors and their respective levels. The first response level in the graphs is "1" and represents the proportion of successes. The second response level is "0" and represents the proportion of failures. Logistic regression can be used to fit a model of the GCE succeeding with all of the predictor variables taken into consideration at once. The remainder of this section will focus on logistic regression to fit a model that will predict the probability of success based on the values of all factors.

1. Fitting a Logistic Regression Model

Using the data obtained from the simulation we now fit a logistic regression model with all factors involved. Using JMP statistical software we get the following model and statistics. Results of the regression model are displayed in Table 16.

Whole Model Test

Model	-Log Likelihood	DF	ChiSquare	Prob>ChiSq
Difference	364.99366	3	729.9873	<.0001
Full	135.83090			
Reduced	500.82456			

RSquare (U)	0.729
Observations (or Sum Wgts)	1080

Parameter Estimates

Term		Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept[0]		30.967429	2.7677038	125.19	<.0001
DOS		-5.9330294	0.5448835	118.56	<.0001
ROP		-14.709671	1.8976935	60.08	<.0001
TC		-17.398851	1.6408563	112.43	<.0001

Table 16. Logistic Regression for Sustainment Success

From Table 16 we see the R-Square statistic is .723 for measure of fit. The equation of the model with the corresponding parameters for the different factors is 30.967 – 5.933*DOS – 14.710*ROP – 17.399*TC. Setting this equation equal to the logit of p we have log(p/(1-p)) = 30.967 – 5.933*DOS – 14.710*ROP – 17.399*TC, where p is the probability of sustainment failure and 1-p is the probability of sustainment success. Solving for p and using the corresponding predictor variables yields Figure 11 and Table 17 below.

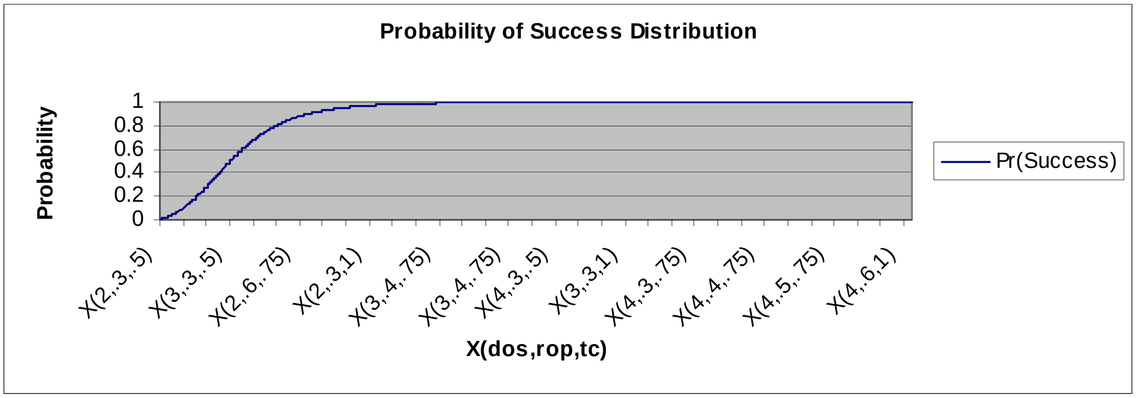

Figure 11. Probability Fit for Success with given Parameter Values

X(dos,rop,tc)	X(2,.3,.5)	X(2,.4,.5)	X(2,.5,.5)	X(2,.3,.75)	X(2,.6,.5)	X(2,.4,.75)	X(3,.3,.5)	X(2,.5,.75)	X(3,.4,.5)
Pr(Success)	0.0025	0.0108	0.0453	0.1626	0.1713	0.4580	0.4860	0.7863	0.8045
X(dos,rop,tc)	X(2,.3,1)	X(2,.6,.75)	X(3,.5,.5)	X(2,.4,1)	X(3,.3,.75)	X(3,.6,.5)	X(2,.5,1)	X(3,.4,.75)	X(4,.3,.5)
Pr(Success)	0.9376	0.9412	0.9471	0.9850	0.9865	0.9873	0.9965	0.9969	0.9972
X(dos,rop,tc)	X(2,.6,1)	X(3,.5,.75)	X(4,.4,.5)	X(3,.3,1)	X(3,.6,.75)	X(4,.5,.5)	X(3,.4,1)	X(4,.3,.75)	X(4,.6,.5)
Pr(Success)	0.9992	0.9993	0.9994	0.9998	0.9998	0.9999	1	1	1
X(dos,rop,tc)	X(3,.5,1)	X(4,.4,.75)	X(3,.6,1)	X(4,.3,1)	X(4,.5,.75)	X(4,.6,.75)	X(4,.4,1)	X(4,.5,1)	X(4,.6,1)
Pr(Success)	1	1	1	1	1	1	1	1	1

Table 17. Probability for Sustainment Success with given Parameter Values

We want to look at the estimates for the individual parameters. Looking at the p-value for the respective Chi-Square statistics we find that all parameters are significant in contributing to the value of the response variable of success. Examining the values of the parameters we can attempt to determine whether any particular factor has more of an impact over the other two factors. The parameters for TC and ROP are proportionally larger than the parameter for DOS. Yet the predictor variables for ROP and TC increase in .1 and .25 increments respectively. So an increased increment in the ROP variable would only result in an approximate -1.47 change in the response variable. A change in the TC variable would result in an approximate -4.35 change in the response variable while an increment in DOS results in a -5.93 change in the response variable. Granted all three factors are significant in the model it confirms the DOS and TC variables have the

greatest significance and impact on the resulting response variable. The variable for ROP, while significant, appears to play a lesser role in determining the outcome of success and failure from the simulation.

The facts that can be concluded from the above analysis are all three predictor variables contribute to determining whether the GCE will successfully accomplish its objectives within the fourteen day time frame. Also, as the values of the factors increase so does the chance of reaching the GCE objectives within the allowed time window. We have shown that the predictor variables contribute to determining success. The next point this thesis will examine is the actual time it takes for the GCE to reach their objectives given the values of the predictor variables.

D. REGRESSION ANALYSIS FOR TIME

Appendix C has the consolidated data this section will be using. The binary responses of “1” and “0” used in the logistic regression have been replaced with the actual times the GCE reached its objectives from the simulation runs. A regression analysis will be computed on the data to determine the significance the factors have on determining the response variable of time. JMP statistical software is used to conduct the regression analysis. The results are displayed in Table 18.

Examining the output data a little closer we see there appears to be a maximum efficiency point that is reached in some of the combination of the factors. Taking the table for four days of supply and noting the columns under the ROP value of 0.6 we notice the ending two-digit decimal values all end in “0” for each run of the simulation. This indicates a perfect run where no delays to the GCE movement occurred due to inadequate organic inventory levels. Sustainment of the GCE was not an issue given the values of the factors. When this occurs the time required to reach the objectives is determined more by the random movement rate of the GCE than its sustainment. This phenomenon also occurs in the some of the columns for the 0.4 and 0.5 ROP values in the table. The conclusion is at some point, no matter how large the factor variables are, the GCE will reach a minimum amount of time it can reach the objectives based on its movement rate. The efficiency point in regards to total time to reach all objectives for

this simulation appears to be between 229.8 and 230.1. With this in mind the regression equation is computed and the results for the response variable of time are displayed below in Table 18.

Response Time
Summary of Fit

RSquare	0.576104
RSquare Adj	0.574922
Root Mean Square Error	60.29773
Mean of Response	285.9342
Observations (or Sum Wgts)	1080

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	5316866.6	1772289	487.4528
Error	1076	3912138.6	3636	Prob > F
C. Total	1079	9229005.2		<.0001

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		704.50144	12.19833	57.75	0.0000
DOS		-66.78503	2.247164	-29.72	<.0001
ROP		-152.2854	16.41096	-9.28	<.0001
TC		-199.5783	8.988655	-22.20	<.0001

Effect Tests

Source	Nparm	F	Sum of Squares	F Ratio	Prob > F	
DOS	1	1	3211373.4	883.2606	<.0001	
ROP	1	1	313076.2	86.1089	<.0001	
TC	1	1	1792417.0	492.9889	<.0001	

Table 18. Regression Analysis for Time Completion

The first thing to note is the R-Square statistic is .576 so the model only captures 57.6% of the variance about the mean. Reviewing the parameter estimates we see the equation of the model is Time = 704.5 – 66.78*DOS – 152.28*ROP – 199.58*TC. The equation would seem to suggest that as the predictor variables increase incrementally the response variable of time will decrease toward the value of zero. However, this is not true. As mentioned above the simulation reaches a point that we consider to be maximum efficiency. We now look at the leverage plots for each predictor value.

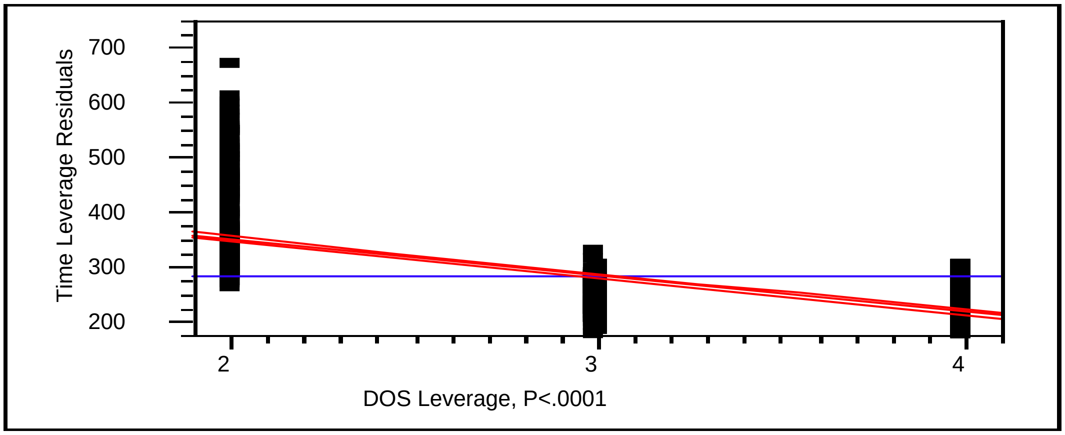

Figure 12. Leverage Plot for DOS

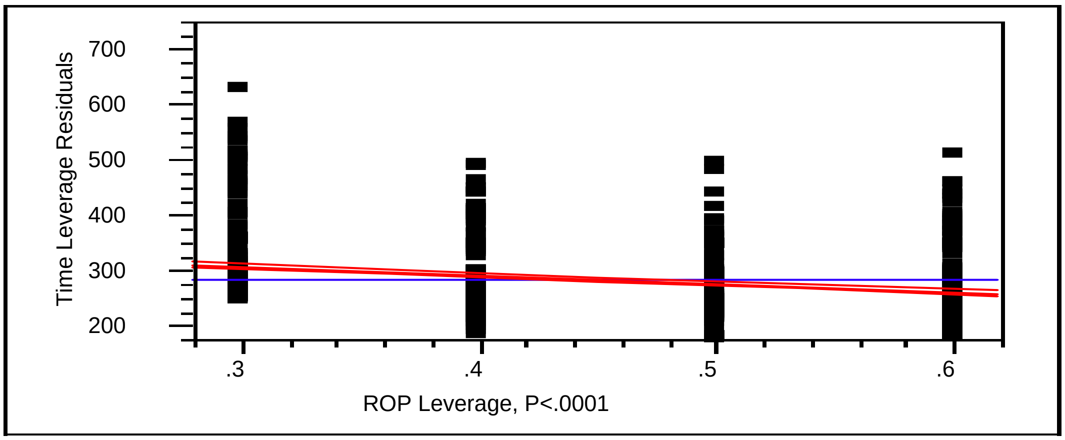

Figure 13. Leverage Plot for ROP

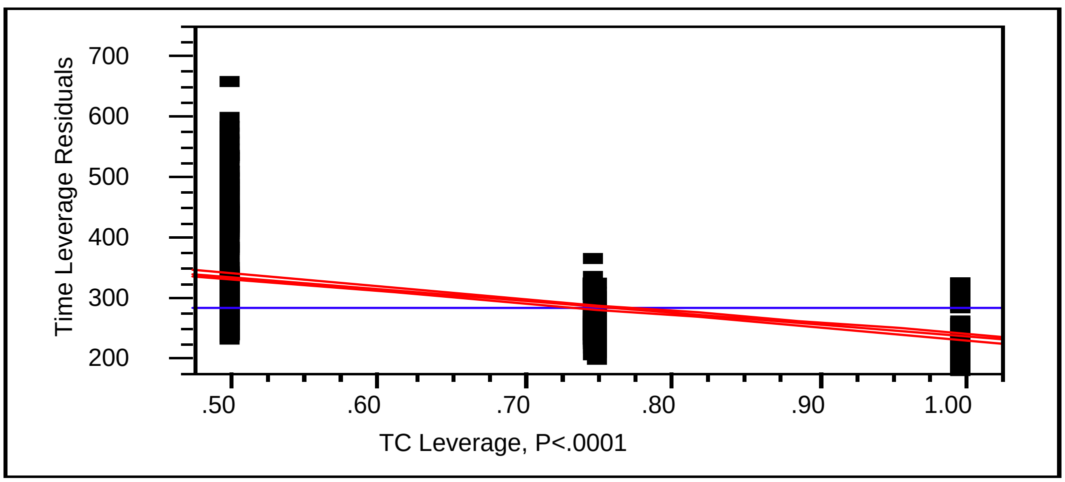

Figure 14. Leverage Plot for TC

The bottom horizontal axis represents the value of the factor. The left vertical axis represents the residual distance from each plotted point to the sloped line in the full model. What the leverage plot shows is how each effect contributes to the fit after all the other effects have been included in the model (Sall, Creighton, Lehman, 2005). These leverage plots provide a graphical reference to the significance of each parameter. Although it may be hard to see in the figures above there are 95% confidence curves surrounding the sloping leverage line that extends through the graph from the left vertical axis to the right vertical axis. These confidence curves represent the full model. Since the leverage line slopes away from the leveraged average (horizontal line that extends though the graph) and each of the confidence curves do not envelope the leveraged average line we can conclude the effects for the individual factors are significant. From the output of statistics in Table 18 above, the factors are all considered to be significant in contributing to the response variable of time in the model. The other takeaway from this analysis is the time required to reach the objectives decreases as the values of the individual factors increase. This is seen in relation to the negative value of the estimated parameters for the factors in the model.

From this analysis we can conclude that the factors do contribute to the response variables. However, due to the R-Square statistic of .57 it would be suspect to assume that any value for the predictors would provide an accurate response variable. Again this is due to the fact that a maximum efficiency point is reached where the simulation no longer becomes dependent on the predictor variables but more on the movement rate of the GCE. Now that the significance of the predictor variables has been demonstrated in both the logistic regression for success and the regression for time it would be important to compare the sample mean times for completion of the objectives with each other.

E. ANALYSIS OF VARIANCE FOR SAMPLE MEANS

The values from Appendix C will again be considered for this analysis. The reason for this analysis is available assets in supplying logistics to the GCE may be limited by unforeseen constraints or events. It would be important to know if the GCE can achieve the same levels of efficiency in the simulation with different combinations of factors. It has been established that the success rate of reaching the GCE objectives

within a fourteen day time period increases as the values of the factors increase as well. It has also been established that the time to reach the objectives decreases as the values of the factors increase. Analyzing the variance of the different sample means will show which combination of factors are equivalent in maximum efficiency.

The data in the tables of Appendix C will be split into three groups. The first group will be all combination of samples involving the value two for DOS. The second group will involve all combinations possessing the value of three for DOS. The third will have all combinations possessing the value of four for DOS. Figure 15 displays a graphical description of the group means for two DOS.

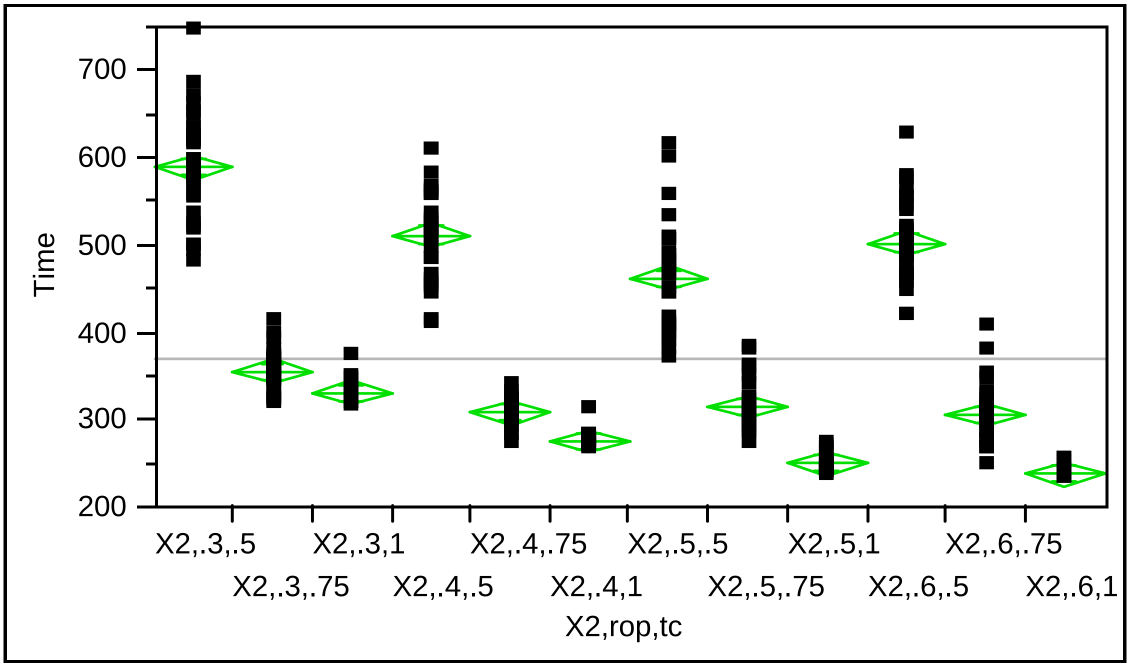

Figure 15. Group Means of Time by Two DOS

The horizontal axis lists the respective sample with corresponding ROP and TC values. The vertical axis lists the time required for the GCE to reach all the objectives. The horizontal line that extends from the left vertical axis to the right vertical axis is the grand mean across the group. The plots show the distribution of times to reach the objectives for each sample. The diamonds are the means diamonds (Sall, Creighton, Lehman, 2005). The mean for the individual sample group is the middle line of the diamond. The vertical tips of the diamonds are the 95% confidence interval for the sample group's mean. There may also be two additional sets of lines in the interior of

each diamond. These additional lines indicate where confidence intervals from another sample mean overlap. If confidence intervals do not overlap the means are considered to be significantly different. Graphs for three and four DOS are shown below.

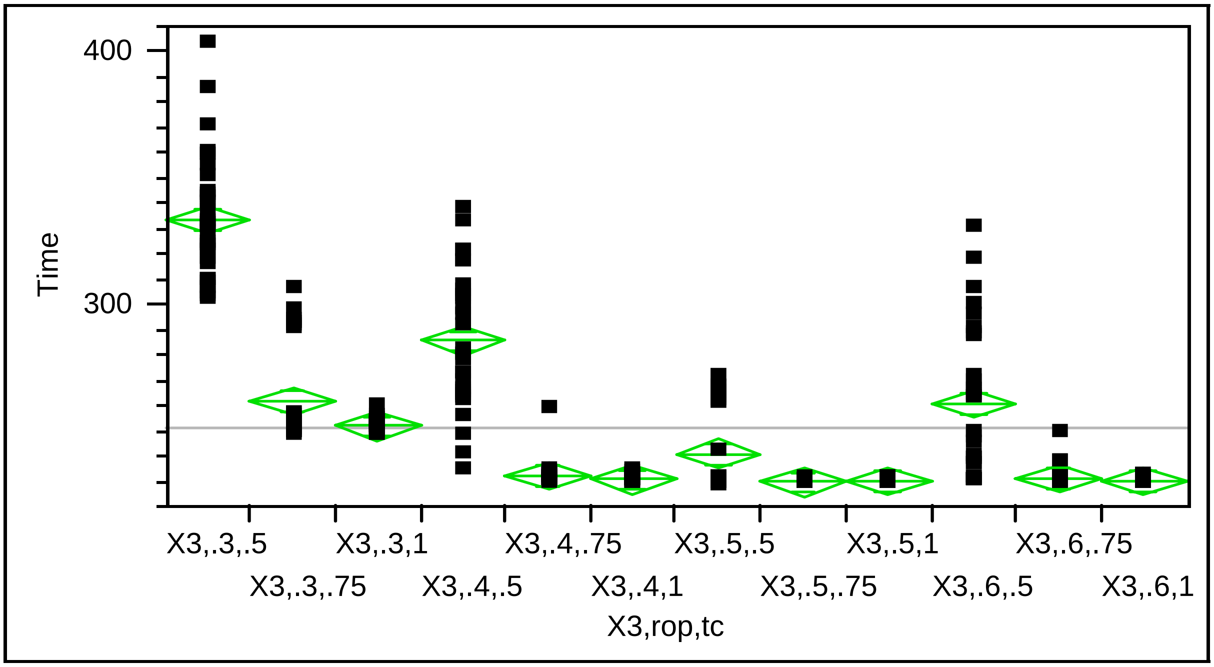

Figure 16. Group Means of Time by Three DOS

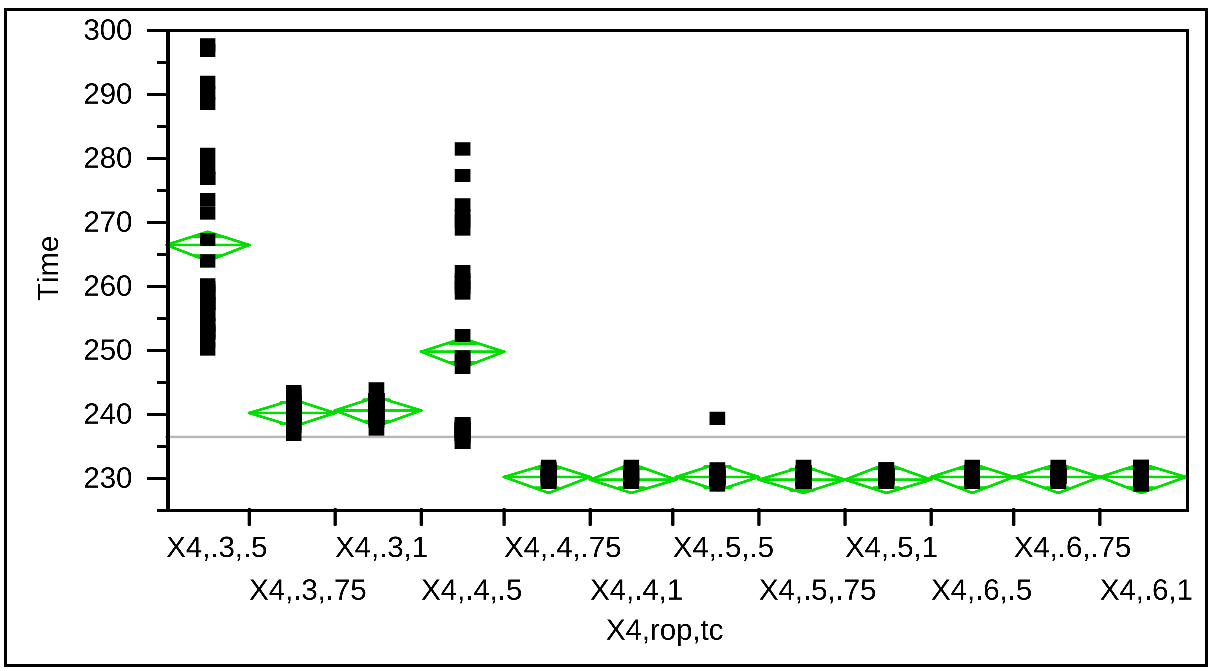

Figure 17. Group Means of Time by Four DOS

The null hypothesis assumes there is no difference in means across the sample groups. The alternative hypothesis assumes at least one sample mean is different among the group of means. Comparing means across twelve sample groups can increase the chances of declaring a difference significant when it really is not. This would be a type I error. In their book JMP Start Statistics, the authors recommend using the Tukey-Kramer Honestly Significant Difference (HSD) test to control for an overall error rate. The test uses the distribution of the maximum range among a set of random variables (Sall, Creighton, Lehman). We conduct the Tukey-Kramer HSD test for each sample group to see which means are significantly different. The result for the sample group involving two DOS is listed first.

Level									Mean
X2,.3,.5	A								588.6752
X2,.4,.5		B							511.6439
X2,.6,.5		B							502.4905
X2,.5,.5			C						462.6055
X2,.3,.75				D					355.3088
X2,.3,1				D	E				330.7796
X2,.5,.75					E				314.2370
X2,.4,.75					E				307.5849
X2,.6,.75					E	F			305.3143
X2,.4,1						F	G		274.6147
X2,.5,1							G	H	249.0755
X2,.6,1								H	237.1803

Table 19. Mean Comparisons using Tukey-Kramer HSD for Two DOS

The resulting comparison table of the Tukey-Kramer HSD shows the sample populations in the left column with their corresponding means in the right column. Sample means not connected by the same letter are considered to be significantly different according to the Tukey-Kramer Test. The two lowest samples in the far left column are not significantly different and are the most efficient in regards to the GCE reaching its objectives with means of 249.07 and 237.18. The next two tables listed below are the Tukey-Kramer HSD tests for both three and four DOS.

In Table 20 the last seven samples are not considered to be significantly different from each other and demonstrate the best efficiency in terms of the GCE reaching its

objectives for three DOS. In Table 21 the last eight samples are not considered to be significantly different from each other and demonstrate the best efficiency in terms of the GCE reaching its objectives for four DOS.

Level						Mean
X3,.3,.5	A					333.5402
X3,.4,.5		B				285.4661
X3,.3,.75			C			261.6008
X3,.6,.5			C			260.6193
X3,.3,1			C	D		251.7720
X3,.5,.5				D	E	240.8223
X3,.4,.75					E	232.0555
X3,.6,.75					E	231.2581
X3,.4,1					E	230.7080
X3,.5,1					E	229.9567
X3,.6,1					E	229.9067
X3,.5,.75					E	229.7467

Table 20. Mean Comparisons using Tukey-Kramer HSD for Three DOS

Level					Mean
X4,.3,.5	A				266.2981
X4,.4,.5		B			249.5934
X4,.3,1			C		240.5377
X4,.3,.75			C		240.1806
X4,.5,.5				D	230.1263
X4,.6,.5				D	230.0900
X4,.6,1				D	230.0733
X4,.4,.75				D	230.0400
X4,.6,.75				D	230.0167
X4,.4,1				D	229.9567
X4,.5,1				D	229.9400
X4,.5,.75				D	229.8167

Table 21. Mean Comparisons using Tukey-Kramer HSD for Four DOS

Taking the most efficient values of each table and performing three more iterations of the Tukey-Kramer HSD test and removing samples that are significantly different after the iterations yields the final table below.

Table 22 shows the combinations that are most efficient in the GCE reaching its objectives that are not significantly different from each other. A quick test to see if the variances are equal is accomplished using JMP statistical software and the results are listed in Table 23.

Level		Mean
X4,.5,.5	A	230.1263
X4,.6,.5	A	230.0900
X4,.6,1	A	230.0733
X4,.4,.75	A	230.0400
X4,.6,.75	A	230.0167
X3,.5,1	A	229.9567
X4,.4,1	A	229.9567
X4,.5,1	A	229.9400
X3,.6,1	A	229.9067
X4,.5,.75	A	229.8166
X3,.5,.75	A	229.7466

Table 22. Mean Comparisons using Tukey-Kramer HSD for Efficient Samples

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
X3,.5,.75	30	0.483331	0.3866667	0.3866667
X3,.5,1	30	0.424007	0.3557778	0.35
X3,.6,1	30	0.658071	0.4746667	0.4666667
X4,.4,.75	30	0.680568	0.5666667	0.5666667
X4,.4,1	30	0.536067	0.3966667	0.3966667
X4,.5,.5	30	1.735688	0.78524	0.6929667
X4,.5,.75	30	0.615368	0.4811111	0.47
X4,.5,1	30	0.459085	0.356	0.3533333
X4,.6,.5	30	0.568937	0.4386667	0.4366667
X4,.6,.75	30	0.511983	0.3988889	0.39
X4,.6,1	30	0.724418	0.5484444	0.5466667

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0057	10	319	0.4383
Brown-Forsythe	0.9236	10	319	0.5115
Levene	1.4559	10	319	0.1549

Table 23. Testing Final Samples for Unequal Variances

The bottom three tests with the corresponding p-values are tests that estimate whether the variances are equal. Small p-values indicate the variances are unequal. The O'Brien test uses the t-test but assumes the means are really variances. The Brown-

Forsythe test measures the differences from the median instead of the mean and then tests these differences. The Levene test estimates the mean of the absolute differences for each sample group and then performs an F-test on those estimates (Sall, Creighton, Lehman, 2005). In the table the smallest p-value is .155 and we conclude the variances are equal. A graph of the final group means with the Tukey-Kramer circles is shown in Figure 18 below. From this analysis we conclude the final set of group means are not significantly different and are the most efficient combinations of factors for the GCE to reach their required objectives. Recalling the logistic regression probability distributions and the leverage plots we know days of supply carried by the GCE contributes the most to the success of the GCE. Transportation capacity within the CSSE also contributes a lot to the sustainment success of the GCE.

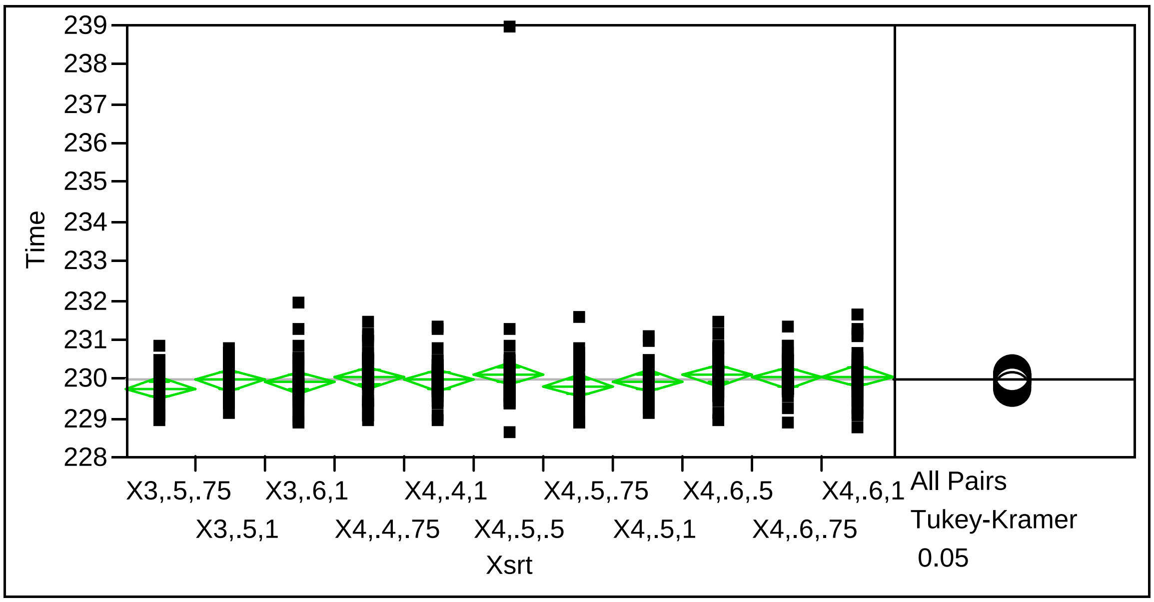

Figure 18. Final Group Means with Comparison Circles

Examining the remaining sample groups and their respective combinations we see that there is no combination with two days of supply that delivers the greatest amount of efficiency. It also appears that the greatest efficiency can be achieved more often if the GCE is capable of carrying four days of supply. In relation to the reorder point there is no combination that involves a reorder point that waits until 30% of the GCE inventory is exhausted before making a request for additional supplies. Intuitively this is sensible because it will require a much shorter time for the GCE to reach its stopping condition if

it waits to request supplies than if it requested supplies while at a 50% or 60% inventory level. The table also shows that the CSSE should have a transportation capacity between 75–100% of what the GCE is capable of carrying in days of supply in order to achieve limited delays in sustainment. It should be mentioned that burdening the GCE with additional days of supply or limiting transportation capacity may be counter productive to the idea of maneuver warfare. This analysis demonstrates options in the combination of factors that can achieve limited delays in sustainment in the simulation if increasing a given factor's value proves not to be a viable option.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

Using Simkit we developed a discrete event simulation based on the defined logistics process to measure the time required by a MEB sized GCE to reach its assigned objectives while being sustained by a CSSE. We asserted the days of supply the GCE is capable of carrying, the point at which the GCE requests supplies, and the transportation capacity available within the CSSE to move supplies all contribute to determining whether the GCE reaches its objectives within a predetermined time window. A full factorial design of thirty-six combinations was developed. Using this design an output of data for the thirty-six combinations was constructed. By performing logistic regression on the data we conclude days of supply, the reorder point, and the transportation capacity resident within the CSSE all contribute significantly to sustaining the movement of the GCE in a manner that allows it to reach the assigned objectives within a fourteen day time frame.

Through regression we showed as the value of the individual factors increase the defined success rate of the GCE increases as well. Using probability distributions of the response variable and leverage plots we can conclude that days of supply and transportation capacity contribute more in determining the time the GCE reaches its objectives. The reorder point still remains as a significant contributing factor but to a lesser degree than the other two factors.

Finally, through analysis of variance and the Tukey-Kramer HSD test of the thirty-two sample means for the time response variable, we can examine the combinations of factors that provide the least amount of delays in sustainment for the GCE in the simulation. These efficiency combinations provide alternative levels in the event that the value of any given factor is constrained from being maximized.

The simulation could be improved to gain more realism. Possible research opportunities to follow this study are as follows:

- A reduction in available transportation capacity or inventory carried by the GCE due to maintenance issues or combat damage is not addressed in this thesis. The effect of an inter-arrival event demonstrating maintenance breakdowns with a wait delay for repair time would be purposeful in determining the effect on sustainment of the GCE.

- The simulation demonstrates the pull method of logistics. In other words, fulfillment of required supplies is not processed by the CSSE until the GCE requests it. By introducing scheduled resupply events into the simulation and pushing supplies to the GCE it would be of interest to note whether factor combinations that did not achieve a minimum amount of delays in the current simulation would approach a more efficient time response.

- Supplies are determined to reach the GCE when the CSSE delivers the supplies to the Mobile Combat Service Support Detachments (MCSSDs) attached to the GCE task forces. If an additional process was introduced into the simulation to model the distribution of supplies from the MCSSDs to the actual combat units it would ostensibly have an effect of increasing the time response to reach the assigned objectives of the GCE.

- The simulation allows only one request to be in the system for a given class of supply. Modifying the simulation to allow updates to the requests in the event the resupply mission has not departed from the established CSSE area could reduce the amount of delays in sustainment.

- The CSSE remains at a fixed position for the duration of the simulation. Studying the effects of moving the CSSE closer to the GCE as the distance between the two elements expands could provide insight in maintaining minimal sustainment delays.

- In this thesis the operational pace was kept constant and the supporting logistic capacity was varied. Using the simulation model a study could be conducted to determine what operational pace is considered unsustainable

when given a fixed supporting logistic capacity. An operational pace can be determined to be outrunning its logistics support capacity when the rate of change ratio between distance moved and time elapsed decreases to an unacceptable level.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. MDC STUDY CONSUMPTION PARAMETERS

Average Demand of Class I and Class V Supply from MAGTF Distribution Center Study	
Class I - Water	**Consumption Factor**
Drinking	4.07gals/man/day
Class I -Chow	**Consumption Factor**
Packaged	3.0 lbs/man/day
Class V	**Consumption Factor**
Small arms	6.5 lbs/man/day
Artillery	23.5 lbs/man/day

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. TCL MODEL PARAMETERS

LogOA Reference Number	Step Description	Shortest Time	Most Likely Time	Longest Time
4	RM sources internally or generates request	0.1	0.5	2
9	OM transforms request into customer order	0.05	0.1	0.25
10	OM checks with ICM to determine availability of supply	0.05	0.1	0.25
11	OM checks with DCM and confirms availability of distribution capacity to support movement requirements	0.1	0.25	0.5
12	OM assesses capability of ICM and DCM to deliver product within the terms and conditions of the RM's request	0.1	0.25	0.5
13	OM reconciles RM terms with ATP/CTP and obtains RM confirmation	0.1	0.5	2
20	DCM and ICM coordinate pickup to meet delivery requirements	0.1	0.25	0.5
26	DPM routes order to appropriate DE for fulfillment	0.1	0.5	2
28	IE picks, packs, and stages order and generates shipping documents	0.5	2	4
29	DE receives the item from the IE	0.25	0.5	1
29.1	DE loads the item onto distribution mode	0.25	0.5	1
29.2	DE transports item to requested location	(Time = Distance/CSSE Movement Rate)		
29.3	DE fulfills distribution service (item is received by RM)	0.25	0.5	1
29.4	DE fulfills distribution service (item is received by using unit)	0.25	0.5	1
30	Item is installed if required	0.5	1	2

Time Criteria Logistics Model, 2004

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. SIMULATION RESULTS

Two DOS											
.3 ROP			.4 ROP			.5 ROP			.6 ROP		
0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
478.116	316.841	315.151	409.494	270.907	266.998	370.499	271.844	236.489	419.136	248.578	231.399
492.010	321.304	316.160	410.847	281.257	267.451	378.692	285.338	237.395	419.563	266.568	231.528
498.051	321.578	316.255	442.082	282.491	268.080	387.555	288.155	238.008	447.465	266.715	231.914
499.064	323.309	317.780	448.668	291.551	268.552	393.583	289.544	238.207	456.564	266.809	232.725
516.997	325.774	317.875	453.355	296.394	269.050	397.042	292.638	239.542	458.749	271.027	232.875
518.565	331.951	320.377	455.069	297.311	269.240	403.777	295.470	240.218	463.802	273.650	233.430
521.454	341.584	322.071	458.989	297.762	269.382	406.350	297.135	240.535	464.901	273.813	233.699
533.614	341.931	322.232	465.356	298.304	270.062	407.105	297.509	240.817	464.925	283.408	233.911
552.585	343.021	322.404	483.321	298.643	270.206	408.244	298.267	241.277	473.479	283.908	233.983
557.371	344.417	322.492	483.521	299.811	270.746	415.124	302.774	241.493	475.310	285.883	234.147
568.397	344.755	323.059	494.670	300.747	270.993	441.471	304.004	242.660	485.786	293.916	234.284
572.443	345.141	323.618	506.133	304.544	271.490	441.912	304.114	242.868	485.951	298.022	234.778
576.186	352.695	324.341	507.431	305.585	272.467	449.747	306.305	243.339	486.624	298.596	234.817
579.284	354.658	324.357	513.053	307.935	274.024	463.590	306.935	243.965	488.152	302.211	234.824
587.826	356.571	325.248	514.797	308.432	274.064	464.881	307.491	245.628	496.020	303.830	234.833
596.101	357.949	325.538	515.634	309.392	274.219	466.293	308.223	246.078	496.500	304.202	234.946
596.937	358.371	326.225	522.952	310.405	274.545	474.481	309.009	246.272	498.963	305.488	235.198
612.556	360.922	329.891	523.150	310.712	274.668	475.384	310.004	246.613	505.712	308.962	235.287
617.675	361.404	331.110	525.415	312.037	275.006	478.631	310.253	247.110	509.241	309.682	235.513
618.365	365.006	331.338	528.108	313.423	275.019	480.082	311.676	247.861	512.679	310.078	235.521
620.646	365.630	337.619	535.453	315.447	275.048	485.571	312.241	249.660	517.555	311.874	235.748
623.016	367.934	342.262	555.713	317.973	275.440	486.124	312.279	251.477	519.092	315.473	235.937
632.020	368.075	342.897	556.324	319.290	275.595	487.929	319.382	257.220	538.781	318.960	235.940
632.020	368.878	343.313	557.816	319.745	275.883	504.597	325.154	261.800	545.026	320.786	237.341
648.682	370.389	343.914	558.225	319.975	277.866	504.893	337.506	263.085	551.517	328.024	240.341
652.060	372.439	344.512	563.089	320.059	278.416	506.959	347.828	266.231	553.974	328.802	242.754
658.401	378.516	346.108	565.397	323.621	279.589	530.618	356.584	267.026	561.906	345.982	249.163
670.382	389.496	346.308	579.986	324.444	281.079	556.731	360.200	267.752	575.683	349.844	252.397
684.722	396.394	347.196	606.761	330.918	282.182	597.658	378.700	269.494	575.941	377.992	252.431
744.710	412.331	371.737	608.508	338.433	311.080	612.641	380.549	272.146	625.718	406.347	253.744

Simulation Results for Factor Combinations Involving Two Days of Supply

Three DOS											
.3 ROP			.4 ROP			.5 ROP			.6 ROP		
0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
301.533	247.749	247.817	234.698	229.400	229.100	228.400	228.900	229.100	229.600	229.100	228.800
302.587	248.724	248.424	241.012	229.600	229.243	229.300	229.000	229.300	229.800	229.100	228.900
303.981	248.877	248.999	248.162	229.700	229.450	229.400	229.000	229.400	230.100	229.200	229.000
306.357	249.268	249.593	255.073	229.800	229.600	229.400	229.000	229.400	230.200	229.300	229.200
308.298	249.602	249.643	261.949	229.900	229.600	229.500	229.100	229.400	230.200	229.600	229.300
309.570	250.080	250.181	262.793	230.028	229.635	229.700	229.200	229.500	231.150	229.600	229.400
309.589	250.102	250.241	263.916	230.100	229.800	229.800	229.400	229.600	231.200	229.600	229.500
315.537	250.204	250.408	264.146	230.228	229.900	229.900	229.500	229.700	236.681	229.700	229.500
317.462	250.470	250.495	264.364	230.366	230.020	230.000	229.500	229.700	236.774	229.800	229.600
321.257	250.549	250.597	265.390	230.385	230.027	230.000	229.500	229.700	238.161	229.900	229.700
322.735	250.610	250.810	269.336	230.500	230.144	230.100	229.600	229.700	238.214	230.000	229.700
323.303	250.931	250.862	271.925	230.507	230.185	230.100	229.600	229.800	239.941	230.100	229.700
323.872	251.574	250.972	272.729	230.643	230.236	230.100	229.700	229.800	245.164	230.100	229.700
327.781	251.762	250.973	277.356	230.800	230.250	230.200	229.700	230.000	246.586	230.300	229.800
330.825	252.126	251.043	279.864	230.840	230.300	230.200	229.700	230.000	248.866	230.300	229.800
331.028	252.338	251.560	282.238	230.916	230.455	230.300	229.800	230.100	262.287	230.400	229.800
331.518	252.342	251.796	291.472	230.996	230.500	230.300	229.800	230.100	262.470	230.400	229.900
332.433	252.858	251.964	295.391	231.242	230.600	230.500	229.900	230.100	263.722	230.400	229.900
336.138	253.075	252.195	298.106	231.501	230.681	230.900	229.900	230.100	265.978	230.500	230.000
339.919	253.122	252.365	301.898	231.731	230.898	231.200	230.000	230.200	266.188	230.600	230.000
341.927	255.667	252.657	302.861	232.052	231.195	241.209	230.000	230.200	269.073	230.700	230.000
342.533	256.124	253.060	303.249	232.189	231.374	260.674	230.000	230.200	271.114	230.700	230.200
343.821	256.383	253.085	304.557	232.206	231.459	262.206	230.000	230.200	287.399	230.700	230.200
350.833	289.910	253.219	307.525	232.210	231.470	262.308	230.200	230.200	287.963	230.700	230.300
354.532	291.486	253.490	316.644	232.557	231.700	264.389	230.200	230.300	290.575	230.900	230.400
358.975	292.505	253.644	317.082	232.608	231.789	264.950	230.200	230.500	295.341	231.000	230.500
359.715	292.765	253.922	320.373	232.676	232.094	265.104	230.400	230.500	300.034	231.500	230.500
370.005	293.235	254.393	320.397	232.985	232.390	266.781	230.400	230.600	306.157	237.097	230.800
385.122	297.868	255.107	332.277	234.453	232.744	267.039	230.400	230.600	317.146	237.422	231.200
403.020	305.719	259.644	337.199	258.547	234.401	270.708	230.800	230.700	330.494	249.023	231.900

Simulation Results for Factor Combinations Involving Three Days of Supply

Four DOS											
.3 ROP			.4 ROP			.5 ROP			.6 ROP		
0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
249.976	236.420	237.224	235.171	228.900	228.900	228.600	228.800	229.100	228.900	228.800	228.700
251.029	237.779	238.442	235.260	229.000	229.000	229.300	228.800	229.200	229.100	229.200	229.000
252.236	238.311	238.677	236.065	229.000	229.300	229.300	228.900	229.300	229.400	229.500	229.100
252.324	238.726	238.856	236.267	229.200	229.400	229.300	229.100	229.300	229.500	229.600	229.200
252.760	238.895	239.033	236.399	229.300	229.500	229.400	229.200	229.500	229.500	229.600	229.400
253.418	239.272	239.124	236.442	229.300	229.600	229.400	229.400	229.500	229.600	229.700	229.400
253.445	239.324	239.351	236.872	229.400	229.600	229.400	229.500	229.500	229.600	229.700	229.500
255.016	239.376	239.415	236.960	229.400	229.600	229.500	229.500	229.600	229.700	229.700	229.600
255.165	239.391	239.527	237.133	229.600	229.700	229.500	229.500	229.600	229.800	229.700	229.700
256.684	239.453	239.585	237.297	229.700	229.700	229.500	229.500	229.800	229.800	229.800	229.700
256.800	239.634	239.736	237.368	229.800	229.700	229.600	229.500	229.800	229.800	229.800	229.800
256.936	239.649	240.227	237.444	229.800	229.800	229.600	229.600	229.900	229.800	229.800	229.800
257.301	239.848	240.561	237.763	229.800	229.800	229.700	229.600	229.900	230.100	229.800	229.900
258.553	239.882	240.803	237.928	229.900	229.900	229.700	229.600	229.900	230.100	229.800	230.000
258.809	240.113	240.955	237.993	230.000	229.900	229.700	229.700	229.900	230.100	229.900	230.100
259.470	240.188	240.981	246.818	230.100	230.000	229.800	229.700	229.900	230.100	229.900	230.100
259.934	240.443	241.137	248.247	230.100	230.000	229.800	229.800	230.000	230.200	230.000	230.100
263.538	240.525	241.173	248.523	230.200	230.000	229.800	229.800	230.000	230.200	230.100	230.100
266.936	240.673	241.182	251.729	230.400	230.100	229.900	229.800	230.100	230.200	230.100	230.200
271.176	240.783	241.185	258.427	230.400	230.100	230.000	229.900	230.200	230.200	230.100	230.200
272.929	240.865	241.228	259.291	230.400	230.100	230.100	230.200	230.200	230.200	230.200	230.300
276.462	241.026	241.363	260.389	230.500	230.200	230.100	230.300	230.200	230.400	230.400	230.300
276.556	241.191	241.480	260.810	230.500	230.200	230.300	230.300	230.200	230.500	230.400	230.400
278.212	241.232	241.793	261.958	230.600	230.300	230.300	230.400	230.200	230.500	230.400	230.500
280.187	241.430	241.830	268.475	230.600	230.300	230.400	230.400	230.300	230.700	230.500	230.600
288.115	241.437	241.835	269.769	230.900	230.400	230.400	230.400	230.400	230.700	230.500	231.000
289.988	241.648	241.860	270.736	230.900	230.400	230.500	230.500	230.400	230.700	230.600	231.100
291.394	242.204	241.941	272.425	231.000	230.700	230.800	230.600	230.400	230.800	230.800	231.200
296.389	242.703	242.028	276.919	231.100	231.200	231.200	230.700	230.900	231.100	230.800	231.600
297.206	242.996	243.598	280.924	231.400	231.300	238.889	231.500	231.000	231.400	231.300	231.600

Simulation Results for Factor Combinations Involving Four Days of Supply

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Buss, A. (2001). Basic Event Graph Modeling. *Simulation News Europe*, Issue 31, April 2001.

———. Discrete Event Programming with Simkit. *Simulation News Europe* Issue 32/33, November 2001.

Concurrent Technologies Corporation (November 2005). *MAGTF Distribution Center Concept Study*.

Decision Engineering (September, 2004). *US Marine Corps Study of Establishing Time Criteria for Logistics Tasks (Final Report)*. Woodbridge, VA

Diesel Fuel Discussions. *http://dodgeram.org/tech/dsl/FAQ/diesel_fuel.html* (July 2006)

US Land Warfare Systems *http://www.fas.org/man/dod-101/sys/land/index.html* (July 2006).

Gary's Combat Vehicle Reference Guide. *http://www.inetres.com/gp/military/cv/index.html#infantry* (July, 2006)

Law, A.M., & Kelton, W. D. (2000). *Simulation Modeling and Analysis* (3rd ed.). Boston: McGraw-Hill

Sall, J., Creighton L., & Lehman A. (2005). *JMP® Start Statistics* (3rd ed.). Belmont, CA: Brooks/Cole-Thomson Learning

TM 11240-15/4C (July 2002) *Motor Transport Technical Characteristics Manual*, Marine Corps Systems Command, Quantico, VA

TM 11275-15/3C (September 1991) *Principal Technical Characteristics of U.S. Marine Corps Engineer Equipment*, Marine Corps Systems Command, Quantico, VA.

U.S. Marine Corps (April 1999). *Marine Corps Warfighting Publication 4-1 (Logistics Operations)*, Marine Corps Combat Development Command, Quantico, VA.

U.S. Marine Corps (February 2003). *Ship to Objective Maneuver Concept of Operations*.

The Weight of Water *http://www.fourmilab.ch/hackdiet/www/subsection1_4_2_0_7.html* (July 2006).

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Marine Corps Representative
   Naval Postgraduate School
   Monterey, California

4. Director, Training and Education, MCCDC, Code C46
   Quantico, Virginia

5. Director, Marine Corps Research Center, MCCDC, Code C40RC
   Quantico, Virginia

6. Marine Corps Tactical Systems Support Activity (Attn: Operations Officer)
   Camp Pendleton, California

7. Director, Studies and Analysis Division, C 45
   Quantico, Virginia

8. Professor Arnold Buss
   Modeling, Virtual Environments and Simulation Institute
   Naval Postgraduate School
   Monterey, California

9. Professor David Schrady
   Operations Research Department
   Naval Postgraduate School
   Monterey, California

10. Norm Reitter
    Concurrent Technologies Corporation
    Johnstown, Pennsylvania

11. Captain Matthew Bain
    Logistics Operations Analysis Division (LX)
    Washington, DC